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Can raw zeolite be used for post harvest pepper seed drying?

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Abstract
This study was carried out to test the use of raw zeolite material in drying freshly harvested pepper seeds. Seeds of three pepper cultivars (Carliston, Kandil Dolma, and Yalova Yağlık) were harvested at maturity (65-70 days after anthesis) in two runs (run 1 and 2) in 2019 and dried at 45°C (machine-drying), in the sun (sun-dried) and with zeolite (1:1, seed, zeolite, rate) until seed moisture was reduced to lower than 10%. The time to safe drying was about 20, 40 and 60-100 hours for machine, sun and zeolite drying, respectively. Germination percentages were not significantly different between the drying methods ($P<0.05$) for all three cultivars. Mean germination time was not affected by drying methods in Yalova Yağlık, but was in both runs for Kandil Dolma and in the second run for Carliston. Drying methods showed insignificant differences ($P>0.05$) in seedling emergence for Carliston and Yalova Yağlık, but were significant ($P<0.05$) for Kandil Dolma in both runs. Mean seedling emergence time (d) also changed among the cultivars. Results indicated that raw zeolite has the potential to be used for safe drying of freshly harvested pepper seeds.

Keywords
Seed germination, Emergence, Zeolite drying, Machine drying, Sun drying

Introduction
Seed drying is a routine process carried out after the harvest of crop seeds. In safe drying, seed moisture should be about 10%. This is done by machine (high-temperature air velocity) or by sun (natural) drying. Machine drying high-temperature cabins or incubators are commonly used. In this method, the drying temperature is controlled and time is regulated accordingly. Sun-drying is more open to changes in relative humidity and air temperature and is therefore uncontrollable (Delouche and Baskin, 1973). Seeds in sun-drying are spread on clothes on the soil, from which soil microbiota, may transfer to seeds (Chesneau et al. 2020). Rain and humidity can also induce seed diseases and accelerate seed-borne diseases (Copeland and McDonald, 1985). Machine-drying requires controlled room drying and continuous energy supply. It is a safe method but involves an economic burden for companies. Sun-drying is cheap but has some risks, such as uncontrollable drying rate, disease infection, and increase in infection due to rain (Berjak, 2006).

Zeolites benefit humanity more than any other mineral group in a variety of ways due to their unique features. Ion exchange, filtration, smell removal, chemical sieve, water softener, and gas absorption are just a few of the functions zeolites are used for (Polat et al., 2004). Zeolites were employed by Anatolia's ancient civilizations for a variety of reasons (Birsoy, 2002). More recently, zeolite material (drying beads) was used for drying and safe storage of various crop seeds (Hay et al., 2012; Hay et al., 2013). Our earlier laboratory experiments and research findings showed that zeolite takes in water up to 20-25% of its weight (Hay et al., 2012). As a result, water evaporates from the substance and binds to the beads without the need for heat. When saturated drying beads can be fully reactivated for reuse by heating (Bradford et al., 2018). This easy "manual" method of encapsulating a product in a sealed container with an amount of desiccant is highly cost-effective for quantities up to around 100 L volume at a time, which is sufficient for vegetable or foundation seeds or grain quantities for small farmers (Timsina et al., 2018). Therefore, this material is very widely used in various chemical products (Dogan, 2003).

In fleshy-fruited vegetables such as pepper, seeds do not undergo natural desiccation and mature seeds have more than 40% moisture since seeds are formed within the fleshy fruits around the placenta. In addition, pepper production in Turkey is affected by reduced seed longevity due to warm and humid air during the last years. Drying in such species may induce seed ageing when high temperature is combined with high seed moisture (Justice and Bass, 1978, Demir et al., 2008). In such cases, the use of zeolite can be an alternative drying method. Zeolite uptakes water at room temperature without high temperature with no energy input (i.e. heating). So it can help dry seeds safely (Nassari et al., 2014). Turkey has very high zeolite production potential from central to western Anatolia (Kırka, Emet, Bigadic¸ Gördes, Cappadocia, Yozgat, Beypazarı, Şile and Kesan) (Helvacı et al., 1987). Zeolite is cheap and easy to find. This study is planned to test whether zeolite can be used as a safe drying agent in pepper seeds harvested after maturity.

Materials and Methods

Plant Material

Pepper cultivars (*Capsicum annuum* L. cvs. Carliston, Kandil Dolma and Yalova Yağlık) were grown in Yalova Atatürk Central Horticulture Research Institute between May and September 2019. The soil structure of the growing field was as follows; EC: 15.02 mmhos/cm, pH: 7.35, Ca: 2.02%, organic matter: 2.23%, P: 135 ppm, K: 560 ppm.

Drying methods

In all three cultivars, 110 flowers were tagged at full-bloom and harvested 65-70 days after anthesis. Run 1 and run 2 were carried out consecutively with about 15 days intervals. Seeds were extracted from the fruits and seed moisture contents were determined according to ISTA (2020) rules. Then seeds were divided into three and dried in a machine at 45°C (in the dark), in an incubator (Nüve ES120 Ankara /Turkey), under the sun and with zeolite (1:1 seed, zeolite). Twenty grams of seeds were spread on filter paper during drying for each method of machine and sun-drying. In zeolite drying, seeds in mesh bags were placed into plastic boxes (26x18x6cm) with a ratio of 1:1 seed to zeolite. Drying was carried out for about 100 hours and frequent weighing was done.

Seed moisture content was estimated by the formula;

Final seed weight (g) = $\frac{\text{Initial weight [100- Final seed moisture (\%)]}}{\text{(g) x [100-Initial seed moisture (\%)]}}$

Seed germination and seedling emergence tests

Seed germination was tested on four replicates of 100 seeds at 25 °C over 14 days. Two mm radicle emergence was counted daily and normal seedlings were counted at 14 days according to ISTA (2020) rules.

The seedling emergence test was conducted on four replicates of 100 seeds in a mixture of turf: perlite at the ratio of 2:1 at 2 cm depth in plastic cups (36x18x6 cm). Cups were left at 23±2 °C in 800 lux white light. Relative humidity was about 70% throughout the emergence test. The emergence test was carried out until 20 days. Normal seedling emergence (no defect was seen) percentages are stated.

Mean germination/emergence time (d) was calculated according to the following formula;

$$MGT/MET = \frac{\sum n.t}{\sum n}$$

where, n = number of seeds newly emerged (2 mm radicle emerged) at time t, t = days from sowing, and ∑n = final germination,

Statistical analysis

Statistical analysis was conducted using the package for Social Sciences (IBM SPSS 21 package program) with analysis of variance. Mean differences between the machine drying, sun-drying and zeolite drying methods were calculated at the 5% level using the Duncan multiple range test.

Results and Discussion

Seed drying rates in the three different methods are given in Figure 1. The fastest drying was observed for machine drying followed by sun-drying in both runs. The slowest drying was seen for zeolite drying. This situation was the same for all three cultivars. Zeolite-drying took about 100 hours for Carliston, <70 h for Kandil Dolma and <50 h for Yalova Yağlık. Differences were observed in different runs. It was observed that the drying rate was slower in run 2 than in run 1.

Germination percentages among drying methods were not significant for Carliston in both runs but were significant in the first and second runs for Yalova Yağlık and Kandil Dolma cultivars (Table 1). Zeolite-drying provided significantly higher (P<0.05) germination in seeds of the first run for Kandil Dolma and the second run for Yalova Yağlık cultivar. Zeolite-drying gave equal or higher germination percentages than machine drying and sun-drying for all cultivars and runs (Table 1).

Zeolite-dried pepper seeds germinated as fast as those of machine-dried and sun-dried seeds. Zeolite-drying even led to significantly (P<0.05) faster germination than the other two methods for Kandil Dolma in both runs. A significant difference was also seen in the second run for the Carliston cultivar (Table 1).

Table 1: Changes in germination (GP, %) and mean germination time (MGT, h) of three pepper seed cultivars after drying by three different methods. Means with different letters for the same parameter of the same cultivar are significantly different at 5%.

	1st Run		2nd Run	
		Carliston		
Drying method	GP (%)	MGT (d)	GP (%)	MGT (d)
Machine-drying	93[ns]	3.0[ns]	71[ns]	2.11[c]
Sun-drying	93	3.1	70	1.84[b]
Zeolite-drying	91	3.1	73	1.42[a]
		Kandil Dolma		
Machine-drying	66[c]	3.9[c]	64[ns]	3.1[c]
Sun-drying	75[b]	3.5[b]	67	2.9[b]
Zeolite-drying	81[a]	3.3[a]	65	2.4[a]
		Yalova Yağlık		
Machine-drying	89[ns]	3.6[ns]	65[b]	2.9[ns]
Sun-drying	89	3.6	72[a]	2.9
Zeolite-drying	89	3.3	72[a]	2.8

Seedling emergence percentages of pepper seeds are presented in Table 2. Statistically significant (P<0.05) difference was only seen in one case among the different drying methods (Kandil Dolma, run 2). The differences in seedling emergence were not significant for any of the other drying methods and cultivars (P<0.05). Mean emergence time was either lowest in zeolite-dried seeds or insignificantly different from the other drying methods (Table 2). Zeolite-dried seeds emerged as fast as those seeds dried with the other methods. Nivethitha et al. (2020) carried out a study on okra seeds dried with zeolite beads which removed much more moisture from the seeds and found results similar to ours.

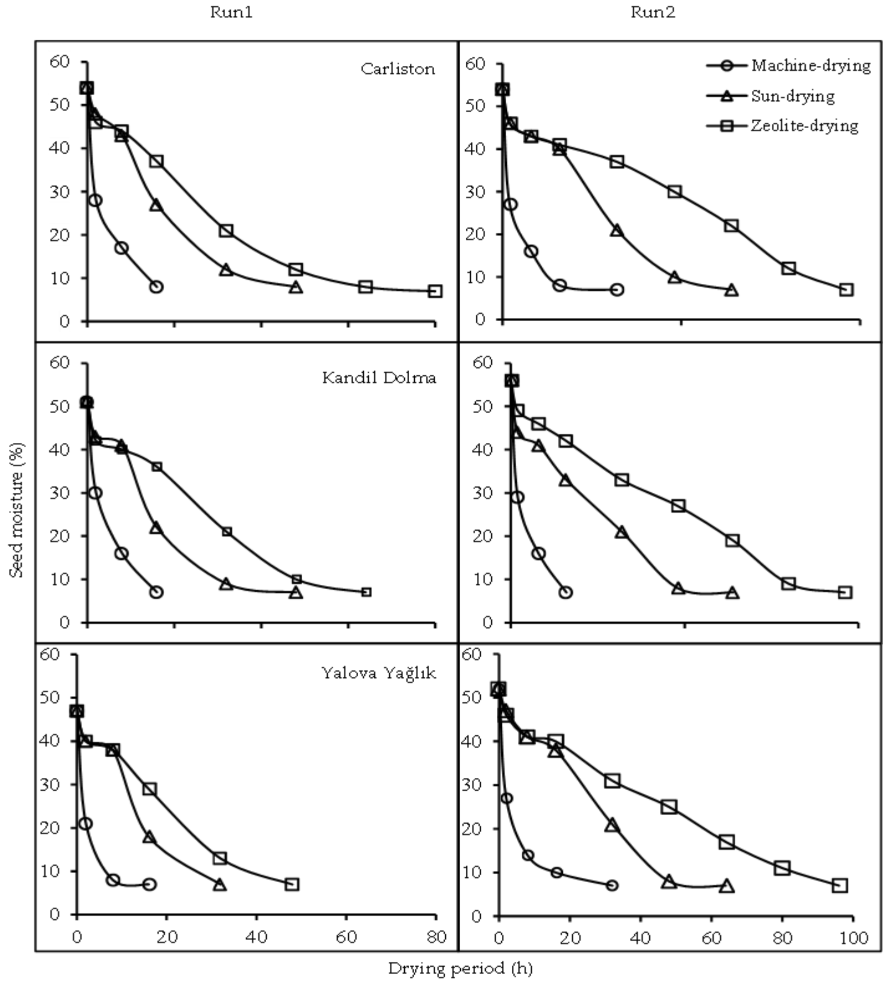

Figure 1. Pepper seed drying rate of three cultivars (Carliston, Kandil Dolma, and Yalova Yağlık) after harvest with machine-drying, sun-drying, and zeolite drying methods in two runs.

Zeolite material, named zeolite beads, have been used to dry rice seeds (Hay et al., 2012; Hay et al., 2013) and some other crops like tomato (Nassari et al., 2014), sorghum (Manish et al., 2015), onion (Timsina et al., 2018), and okra (Nivethitha et al., 2020) and to keep the material dry during storage. However, in our study, we used raw zeolite to dry seeds just after harvest from peppers. Pepper is a fleshy-fruited vegetable and seeds mature in a fleshy fruit and have more than 40% seed moisture at harvest (Demir and Ellis, 1992). In this work, seeds had about 48-54% seed moisture when matured (Figure 1). Using zeolite material to dry seeds down to 10% from such high seed moisture is a new approach. This took a longer time than machine or sun-drying but within about 4 days seed moisture was reduced to below 10%, which is a safe moisture level to store seeds on a commercial scale (Vertucci, 1989).

Pepper seeds are sensitive to high-temperature drying since they have high seed moisture at maturity (Demir, 2002). Exposure to high temperatures when seed moisture is high can reduce seed quality. Therefore, safe dying is important for high quality seed production (Demir and Ozçoban, 2007). In this sense, the use of zeolite provides an advantage by drying the seeds at room temperature. This has two advantages of 1) energy-saving and 2) less risk for seed quality. Our results indicated that raw-zeolite successfully reduced pepper seed moisture at room temperatures without needing machine-drying or sun-drying (Figure 1).

Various cultivars may react differently to drying methods. In general, pepper seeds have a short storage life and are especially sensitive to seed moisture levels. In addition, pepper seeds are produced in our country, especially in humid regions (i.e. Mediterranean region). However, air drying may frequently be insufficient in humid areas, necessitating the use of extra drying processes. In this research, Kandil Dolma appeared to be the most sensitive cultivar. In this cultivar, the lowest seed germination and the longest mean germination time were observed (Tables 1 and 2). Kandil Dolma was reported to be a sensitive cultivar to earlier seed quality loss (Basak et. al., 2006).

For all cultivars, the difference in seedling emergence and mean emergence time between drying procedures were not significant in the first run of the tests, but for the second run of the cultivars Carliston and Yalova Yağlık, it was significant ($P<0.05$) in both of the trials for mean emergence time (Table 2).

Table 2. Changes in seedling emergence (SE, %) and mean emergence time (MET, d) for three pepper seed cultivars after drying with three different methods. Means with different letters for the same parameter of the same cultivar are significantly different at 5 %.

	1. Run		**2. Run**	
		Carliston		
Drying method	SE (%)	MET (d)	SE (%)	MET (d)
Machine-drying	89^{ns}	9.3^{ns}	81^{ns}	7.8^{c}
Sun-drying	93	9.2	75	7.5^{b}
Zeolite-drying	91	8.3	79	6.9^{a}
		Kandil Dolma		
Machine-drying	85^{ns}	11.5^{ns}	81^{a}	10.9^{ns}
Sun-drying	88	11.3	75^{b}	10.7
Zeolite-drying	89	10.9	72^{b}	10.5
		Yalova Yağlık		
Machine-drying	92^{ns}	9.6^{ns}	92^{ns}	8.7^{b}
Sun-drying	89	9.2	93	8.7^{b}
Zeolite-drying	91	9.2	92	7.7^{a}

Conclusion

In conclusion, raw zeolite can be an alternative seed drying method. This is more important in crops where seeds do not undergo natural desiccation on the plant, such as pepper. The seeds might be kept for longer periods without losing their viability or vigor. Recently, new and better quest for drying seeds usually energy consumption and drying control to the availability focused. The economic potential of introducing contemporary drying and packaging technologies to increase the benefits of seed systems can be achieved by drying raw zeolite for seeds. Furthermore, farmers in colder climates can dry their seeds regardless of sunlight or temperatures. Some crop seeds have very high seed moisture which makes them sensitive to high temperature and fast drying. This seed drying method may also be used to preserve germplasm for prolonged storage. Further studies about various fleshy-fruited vegetables will be helpful to obtain applicable results for seed technology.

Compliance with Ethical Standards

Conflict of interest

All authors declare that they have no conflicts of interest

Author contribution

Cihat Ozdamar carried out germination and emergence test in the lab. Kutay Coşkun Yıldırım carried out the growing and harvesting of pepper varieties on the field. Sıtkı Ermiş participated in the design of the study and performed the statistical analysis and helped draft the manuscript. Ibrahim Demir conceived the study, wrote the text and participated in its design and coordination. All authors read and approved the manuscript.

Ethical approval
Ethics committee approval is not required.
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Data availability
Not applicable.
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