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Research Article

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Allelopathic Effects of Selected Culinary Spices and Their Preparation Methods on Wheat (*Triticum aestivum* L.) Seed Germination and Early Seedling Development

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Spices are widely recognised not only for their culinary and medicinal properties, but also for their bioactive compounds that can influence plant growth and development. Recent studies have highlighted the potential of certain spices to exhibit allelopathic or antifungal properties that may affect seed germination and seedling establishment. However, the specific effects of different spices and the influence of their preparation methods on cereal crops such as wheat remain underexplored. This study investigates the effects of selected culinary spices and their forms of preparation on wheat seed germination to assess their potential use in sustainable agriculture as natural seed treatments. This study aimed to evaluate the effects of selected culinary spices on germination and early seedling development of wheat (*Triticum aestivum* L.). Five commonly used spices – garlic (*Allium sativum* L.), ginger (*Zingiber officinale* Roscoe), cinnamon (*Cinnamomum verum* J.Presl), black pepper (*Piper nigrum* L.), and cayenne pepper (*Capsicum annuum* L.) – were tested in different preparation forms, including macerates, infusions, and decoctions. The results showed that black pepper had the most pronounced inhibitory effect on seed germination, with the infusion reducing germination by almost 68% compared to the control. Cinnamon also significantly suppressed germination, especially when applied as a macerate, reducing germination by approximately 39%. Granulated garlic macerate showed a dual effect, strongly inhibiting seedling development, while garlic decoction unexpectedly enhanced seed germination and seedling vigour. Ginger macerate had only a slight inhibitory effect, while chilli macerate slightly stimulated germination, but these effects were not statistically significant. Overall, none of the spice treatments significantly improved germination energy. Statistical analysis confirmed that the type of spice had a significant effect on germination rates ($p = 0.030$), while the method of preparation showed borderline significance ($p = 0.055$). Comparison of treatments showed that the effects of chilli and ginger were not statistically significant ($p > 0.05$), while those of black pepper, garlic, and cinnamon were highly significant ($p < 0.05$). These results confirm the allelopathic and antifungal potential of certain culinary spices, but also show that the biological activity of these spices is highly dependent on the extraction method used. The dual nature of garlic treatments and the pronounced inhibitory effects of black pepper and cinnamon suggest that their application in agriculture should be carefully optimised. The results highlight the potential for the development of environmentally friendly spice-based seed treatments, but also point to the need for further studies to determine appropriate concentrations and safe application methods that ensure both pathogen control and minimal phytotoxicity.

Keywords: wheat germination, culinary spices, allelopathy, antifungal activity, garlic, black pepper, cinnamon, ginger, hot pepper

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Introduction

Modern agriculture places increasing demands on the quality of crop seeds. Seed enhancement techniques can improve the value of seeds for planting. The most effective method of protecting crops against pests and diseases is the use of chemical seed treatments, although farmers are increasingly seeking to move away from these methods by practising organic farming. The increasing awareness of farmers creates a need to look for new ways of environmentally friendly seed improvement technologies (Orzeszko-Rywka et al., 2010). One such method could be the use of common spices as seed dressings. The main objective of commercial crop production is to achieve a high germination rate, as well as healthy and uniform seeds within a short period. For this purpose, seed dressing processes are applied using substances capable of stimulating seeds for faster growth (Pill, 1995; Taylor et al., 1998; Arin and Arabaci, 2019).

Since ancient times, spices and herbs have been widely cultivated in many countries, particularly in South-East Asia, with India being the largest producer. Spices are mainly added to food to provide aroma and enhance flavour. Some of them (e.g., cayenne pepper or black pepper) contain pharmacologically active substances (Jensen-Jarolim et al., 1998; Chen and Bahna, 2011).

Capsaicin, found in *Capsicum* spp. including hot peppers not only adds flavour and heat to dishes, but is also used for medical and therapeutic purposes due to its numerous pharmacological and physiological effects on humans and animals (Surh and Lee, 1995; Abdel-Salam et al., 1997; Kogure et al., 2002; Luo et al., 2011). Although the physiological role of capsaicin in plants is not fully understood (Aza-Gonzalez et al., 2011; Arin, 2018), it is used in agriculture for weed control due to its allelopathic effects (Gonzales et al., 1997), in seed germination and promotion of faster root and shoot growth in several plant species (Cho et al., 1992; Kato-Noguchi and Tanaka, 2003; Siddiqui and Zaman, 2005), and may be useful as a biopesticide due to its antifungal properties (Kraikruan et al., 2008; Neves et al., 2009; Aza-Gonzalez et al., 2011).

Black pepper (*Piper nigrum* L.) is one of the most popular spices in the world and is native to southern India (Nair, 2011). The main bioactive compound in black pepper is piperine (Taqvi et al., 2008). It is used in traditional medicine, perfumery, preservatives, and insecticides (Raja and Sethuraman, 2008). It is also used in plant breeding to develop varieties with improved organoleptic and nutritional properties (Ashokkumar et al., 2021). In addition, piperine has been reported to have insecticidal and antimicrobial properties, which may support its use as an organic seed treatment agent.

Allicin, a sulphur-containing natural compound with numerous biological properties, is found in garlic and is increasingly used in medicine and agriculture (Slusarenko, 2008). Reports of the deliberate use of garlic as an antimicrobial agent date back to the famous Louis Pasteur (Borlinghaus et al., 2014), and garlic extracts were used in antibacterial and antiseptic therapy during the First World War (Rabinkov, 1998). According to Borlinghaus et al. (2014), root growth is inhibited by allicin without killing the entire plant, indicating that root functions such as water and nutrient uptake remain operational. This makes allicin a potentially selective agent for controlling pathogens while maintaining plant vitality.

Ginger is one of the most widely used spices and contains several interesting bioactive compounds with health-promoting properties. One of these is (6)-gingerol, which has pharmacological activities such as antioxidant and anti-inflammatory effects (Surh, 2002; Wang et al., 2003). This compound also has beneficial effects on plants, acting as an antibacterial, antifungal, and pest repellent, especially against aphids, nematodes, and mites (Kędzia and Kędzia, 2019). In addition, ginger extracts have shown promising activity in improving seed vigour and seedling growth, although more systematic studies are needed in this area.

The last spice studied is cinnamon. Cinnamaldehyde is the major bioactive compound of cinnamon bark oil, which has been studied for its anticancer, antimicrobial, and anti-inflammatory activities in humans (Kim et al., 2020; Mohammadzamania et al., 2020). This compound has also shown beneficial effects on plants, with antibacterial and antifungal activity (Singh Neelabh, 2020; Thirapanmethee et al., 2021). Cinnamon oil is also used as an insect repellent (Orzeszko-Rywka et al., 2012). Some studies also suggest that cinnamaldehyde may stimulate seedling growth by enhancing metabolic pathways involved in early seedling development, although the mechanisms are not fully understood.

In the context of sustainable agriculture and organic farming, these natural, plant-derived compounds could provide environmentally friendly alternatives to synthetic seed treatments. However, scientific validation of their efficacy, optimal concentrations, and potential phytotoxic effects is required before their wider application.

Therefore, the present study aimed to evaluate the efficacy of winter wheat seed treatment with natural, commonly available spices – ground hot pepper, freshly ground black pepper, granulated garlic, ground ginger and ground cinnamon – which, due to their biological activities, could be used as candidates for the development of new environmentally friendly seed treatments.

Materials and Methodology

Plant Material and Treatment Preparation

Winter wheat (*Triticum aestivum* L.) seeds, cultivar 'Euforia', were purchased from a garden shop in Słupsk, Poland. The seeds were treated by soaking in the prepared solutions for 24 hours. Five spices were used in the experiment: cayenne pepper (*Capsicum annuum* L.), garlic (*Allium sativum* L.), black pepper (*Piper nigrum* L.), ginger (*Zingiber officinale* Roscoe), and cinnamon (*Cinnamomum verum* J.Presl). For each spices, three types of extracts were prepared: macerate, infusion, and decoction, according to generally accepted preparation standards. Macerate: prepared by soaking the spice in cold distilled water for 24 hours at room temperature. Infusion: prepared by pouring boiling distilled water over the spice and leaving to infuse for 30 minutes. Decoction: prepared by boiling the spice in distilled water for 15 minutes and then cooling to room temperature. To compare the effectiveness of the treatments tested, a control group was established by soaking the seeds in distilled water only.

Experimental Design

Treated seeds were placed in plastic trays measuring 216 × 108 × 45 mm, previously lined with medium filter paper folded in an accordion shape. In each tray, 100 treated seeds were evenly distributed, and each treatment was replicated in triplicate. All trays were placed in a controlled environment phytotron chamber set at 20 °C and 70% relative humidity. The experimental conditions followed the International Seed Testing Association (ISTA) methodology.

Germination Evaluation

The parameter measured in the study was germination capacity, defined as the percentage of seeds that successfully germinated under the specified conditions. Seed treatment and germination assessments were carried out at the Geological and Soil Science Laboratory of the University of Pomerania in Słupsk (Słupsk, Poland).

Statistical analysis

The experimental data were statistically processed by calculating: mean ($\bar{x}$), standard deviation (SD), minimum (min), and maximum (max) values. Student's *t*-test was used to compare the treatment groups with the control. One-way analysis of variance (ANOVA) was used to assess the differences between the different spice treatments. Tests were performed using Statistica software, version 13.3 (TIBCO Software Inc., USA). A *p*-value less than 0.05 ($p < 0.05$) was considered statistically significant.

Results and Discussion

Figure 1 shows the percentage of germinated wheat seeds as a function of the spice used. Analysing the data, it can be seen that paprika (*Capsicum annuum*) showed no deviation from the control (81%). Ginger (*Zingiber officinale*) and cinnamon (*Cinnamomum verum*) slightly reduced wheat germination to 64% and 62%, respectively. Granulated garlic (*Allium sativum*) reduced wheat development by 32%. The most effective inhibitor was freshly ground black pepper (*Piper nigrum*), which reduced germination to 41%. None of the spices significantly increased germination energy.

Our results show that there are differences in both the type of spice used and the method of its their preparation. Statistical tests were performed, including the Shapiro-Wilk test, which indicated that the data followed a normal distribution. Statistical analysis confirmed that the factor of spice type was statistically significant ($p = 0.030$), while the factor "type of preparation" was borderline statistically significant ($p = 0.055$). Using a one-way ANOVA test for spice type, it was found that the results for hot pepper and ginger were not statistically significant ($p > 0.05$). However, the results for the other three spices – black pepper, granulated garlic, and cinnamon – were statistically significant ($p < 0.05$).

Figure 2 presents data on the percentage of germinated wheat seeds as a function of spice type and preparation method.

Analysis of the results shows that certain spices have an inhibitory effect on wheat germination. The most pronounced effect was observed with the infusion of black pepper, which led to a reduction in germination of almost 68%. Cinnamon macerate was the second most effective method of inhibiting wheat germination (39 ±7% reduction). Another example was the black pepper macerate, which caused a reduction of about 44% (Figure 2).

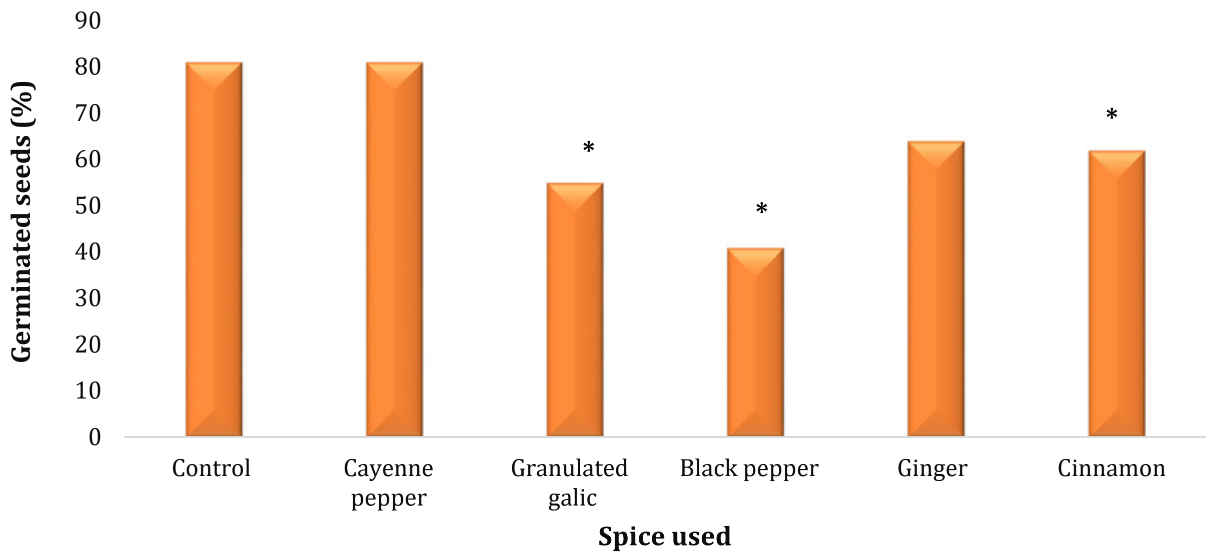

Figure 1 Average number of germinated seeds after use of spices
* – changes were statistically significant compared to control

Figure 2 also shows that in three cases, the germination process was accelerated. The highest value was obtained with the decoction of granulated garlic (86 ±10%). A similar result was obtained with the hot pepper macerate (85 ±5%) and the cinnamon decoction, which increased germination by 2.5% compared to the control, but these differences were not statistically significant. Neither the decoction nor the infusion of hot pepper showed any significant effect (about 79% germination). The remaining treatments also inhibited germination to varying degrees, ranging from 12 to 40% (Figure 2).

This study used five common culinary spices that are used in everyday cooking around the world. Garlic was chosen for its content of allicin, a compound known for its many health benefits, including antifungal activity, which should be reflected in the health status of treated seeds. Our research showed that garlic can also affect seed germination. In our case, it acted in two ways: the macerate significantly reduced seedling development, while the decoction accelerated seed growth compared to the control. Perelló et al. (2013) also used garlic in their studies on wheat, reporting strong antifungal activity along with improved seed germination. However, in their research, the treatment was prepared from freshly pressed garlic. In a study by Golubkina et al. (2024), garlic extract was used to prime lettuce seeds (*Lactuca sativa* L.). However,

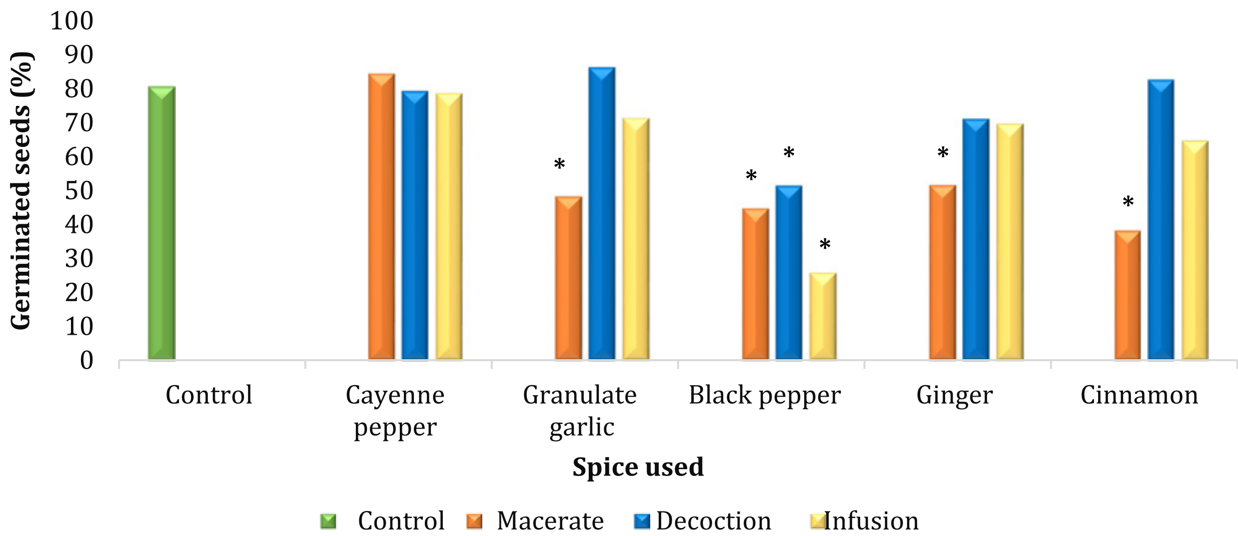

Figure 2 Dependence of the sprouted seeds on the type of spice used and the method of preparation
* changes were statistically significant compared to control

in this case, the treatment did not result in any significant changes to seed germination capacity or energy. Despite the lack of effect observed in this study, garlic's antimicrobial and antifungal properties have been well-documented in the literature (Curtis et al., 2004). This is further supported by Slusarenko et al. (2008) research, in which carrot (*Daucus carota* L.) seeds infected with the fungus *Alternaria alternata* Keissl. were treated with garlic juice and then dried. This successfully eliminated the fungal infection and increased the germination rate.

Similarly, ginger was another spice analysed in our study due to its reported bioactive properties. Kadhum and Altameemi (2010) tested powdered ginger at different concentrations applied to soil. Their study did not show statistically significant effects of ginger on seedling growth or germination inhibition, but they did observe an increase in shoot length and leaf dry mass with ginger application. Our study also showed no major differences in seedling growth rates, with only the ginger macerate showing a slight inhibition of germination. Oltenacu et al. (2022) conducted a study in which they treated seeds of *Capsicum annuum* cv. Barbara with ginger root juice at various concentrations (1%, 5% and 10%). At all three concentrations, the treatment resulted in an increase in germination rate of approximately 33% compared to the untreated control group. However, in our experiments, the results obtained were very similar to the control. This discrepancy may be due to the use of a different plant species in the germination tests, or it may indicate the need to repeat our study under more controlled conditions to verify the observed outcomes. Furthermore, several studies have confirmed the antimicrobial activity of ginger extracts against the fungus *Alternaria alternata* when used for seed treatment (Fawzi et al., 2009; Osman et al., 2016; Ahmad and Qureshi, 2017). These findings support the potential of ginger-based treatments as natural alternatives for managing seed-borne fungal pathogens.

In the case of cinnamon, both the macerate and infusion tested in our experiment delayed wheat germination. These results are in agreement with those of Rozhkova et al. (2021), who reported a complete inhibition of germination when seeds were treated with cinnamon essential oil, in contrast to the 100% germination observed in the control group. The inhibitory effects of cinnamon can be attributed to its bioactive constituents, such as eugenol, which is known for its cytotoxic properties that can suppress plant growth. In addition, cinnamaldehyde, another major constituent of cinnamon, disrupts metabolic processes and exerts strong allelopathic activity, ultimately inhibiting radicle development (Zheljazkov et al., 2021). Kowalska et al. (2019) conducted a study on tomato (*Solanum lycopersicum* L.) seeds to evaluate the antifungal properties of cinnamon water and its impact on plant growth. For this experiment, the authors prepared cinnamon water using their own methodology. This treatment improved plant resistance to diseases and had a positive impact on growth parameters. Six weeks after foliar application, the fresh weight of plants treated with cinnamon water was significantly higher than that of the untreated control group. Similarly, Horváth et al. (2013) reported that cinnamon essential oil effectively inhibited the growth of fungal mycelium on winter wheat (*Triticum aestivum* L.) ears. Several other studies have confirmed the strong antifungal activity of aqueous cinnamon extracts and cinnamon essential oil in suppressing fungal mycelium development (Shabana et al., 2015; Allam et al., 2017; Moraes et al., 2018; Sarkhosh et al., 2018). Enhanced seed health resulting from cinnamon treatments may also contribute to increased germination rates. Additionally, Kowalska et al. (2019) observed that cinnamon treatments promoted plant growth and branching under field conditions. These findings are consistent with the results of our study, in which the use of cinnamon decoction was found to have a positive effect on germination and early seedling development.

Furthermore, our study also highlighted the effects of chilli pepper, where an acceleration of germination was observed. This stimulatory effect may be related to the presence of capsaicin, a compound known to enhance seed protection against pathogens. Although literature data on the application of hot pepper to wheat seeds are scarce, Arin and Arabaci (2019) showed that low concentrations of capsaicin (0.1 ppm) applied to pepper seeds accelerated germination and increased seedling vigour, while high concentrations (100–200 ppm) completely inhibited seed germination. Another interesting experiment was conducted by Barchenger and Bosland (2016), who investigated the effects of treating seeds with an alcoholic solution of capsaicin on two sweet pepper cultivars (*Capsicum annuum*) that do not naturally produce capsaicin: Keystone Resistant Giant Bell Pepper and Pimiento. As the authors anticipated, applying capsaicin led to an increase in seed germination rates over time compared to the untreated control. Furthermore, the study revealed that different concentrations of capsaicin had varying effects on germination performance, depending on the cultivar tested. This suggests a possible cultivar-specific sensitivity to exogenous capsaicin, which may be linked to the seeds' inherent physiological and metabolic characteristics.

Finally, black pepper was the last spice analysed in our study, mainly because of its content of piperine, which is known for its allelopathic effects that can inhibit seed germination. Consistent with this, all black pepper treatments in our experiment led to a reduction in the percentage of germinated seeds. In support of these findings, Ogbonmwan and Al-Faraj (2023) reported that treatment of wheat seeds infected with *Rhizopus* sp. and *Aspergillus niger* with black pepper preparations effectively eliminated the pathogens and consequently increased seed germination. However, Eldoksh et al. (2023) showed that the effect of black pepper essential oil and pure piperine on seed germination varied significantly with the concentration applied, highlighting the importance of dosage in modulating the allelopathic effects of this spice.

Conclusions

The study demonstrated that commonly used culinary spices have diverse effects on wheat seed germination and early seedling development, highlighting their potential allelopathic and antifungal properties. Garlic, especially in the form of a decoction, showed dual activity, stimulating seedling growth while its macerate exerted inhibitory effects, suggesting that the preparation method significantly influences its biological activity. Ginger showed only a slight inhibitory effect on germination when used as a macerate, in agreement with previous studies indicating a minimal effect on seedling growth parameters. Cinnamon showed the most pronounced inhibitory effect, delaying seed germination regardless of the extraction method used. This supports the hypothesis that its bioactive compounds, such as cinnamaldehyde and eugenol, play a key role in suppressing seedling development due to their cytotoxic and allelopathic activities. Conversely, chilli pepper showed a stimulating effect on germination, which may be due to the protective action of capsaicin, although further studies are needed to investigate its influence specifically on wheat. Black pepper, known for its allelopathic potential due to the presence of piperine, consistently reduced germination rates in all treatments tested. However, literature data suggest that black pepper preparations, when applied at appropriate concentrations, may also have protective effects against seed pathogens, thereby improving germination outcomes in infected seeds.

Overall, the results of this study highlight the complexity of plant-plant interactions mediated by spice-derived compounds and underline the importance of both the type of spice and the method of extraction in modulating their biological activity. These results may have practical applications in the development of environmentally friendly seed treatments, although further research is needed to optimise concentrations and formulations to balance antifungal benefits with potential phytotoxicity to seeds.

Conflicts of interest

The authors have no competing interests to declare.

Ethical statement

This article does not include any studies that would require an ethical statement.

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