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Weed seeds in pelletized chaff do not germinate

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Abstract: Material exiting the harvester is composed of chaff and straw. Chaff is a by-product of grain harvest comprises weed seeds and husk. Harvest Weed Seed Control (HWSC) systems aim at collecting and/or killing weed seeds in the chaff fraction during crop grain harvest. If chaff is removed or processed via impact mills or concentrated in a narrow zone in the field and collected, the overall weed infestation may be reduced in the following years. Chaff may be used as a new biomass feedstock, for example, as a renewable energy source, material for construction (*e.g.*, insulating boards, cardboard, bedding), soil improvement (*e.g.*, mulch, mushroom compost), and for agricultural purposes (*e.g.*, weed growth inhibitor, animal diet). Using chaff directly is unfavorable because of its low bulk density. Therefore, compressing chaff into pellets can improve its handling. In this preliminary study, we assessed how pelletizing would affect the germinability of weed seeds in the chaff pellets. Whole wheat chaff and fine wheat chaff sieved were mixed with seeds of the two weed species scentless mayweed (*Tripleurospermum inodorum* (L.) Sch.Bip.) and cornflower (*Centaurea cyanus* L.), respectively. While 22% of *T. inodorum* seeds and 59% of *C. cyanus* seeds in wheat chaff samples were able to germinate, no weed seeds germinated from moist pelletized original and fine wheat chaff samples. The study indicates a low risk of spreading weed seeds with pelletized chaff probably because the heating during the pelletizing process kills the weed seeds.

Keywords: Harvest residues; Harvest weed seed control; HWSC; Pellet production; Densification; Wheat chaff

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1. Introduction

A conventional combine harvester collects most of the seeds retained on the weed plants at crop harvest and separates the majority of the weed seeds, together with the chaff, from the grains. Afterwards, it expels the weed seed fraction mostly in the chaff and returns it to the field, where they could potential germinate and cause further weed problems in the subsequent growing seasons. In recent years, harvest weed seed control (HWSC) has been adopted in many places in the world to reduce weed infestations on arable fields (Tidemann et al., 2017; Walsh et al., 2018). This process takes advantage of seed retention at maturity by collecting weed seeds as they pass through the combine harvester. The seeds can then be removed from the field or destroyed immediately using a seed destructor, which is an aggregate placed behind the combine, pulverizing and destroying seeds (Walsh et al., 2012), or other methods (Jakobsen et al., 2019). Problematic weeds like cleavers (*Galium aparine* L.) retained 100% of their seeds at wheat harvest in Denmark (Glasner et al., 2019); rigid ryegrass (*Lolium rigidum* Gaud.) retained 85% at wheat harvest in Australia (Walsh, Powles, 2014), and Italian ryegrass (*Lolium perenne* L.) retained 58% at wheat harvest in the United States (Walsh et al., 2018) showing that they are creating an ideal opportunity for seed collection during the grain harvest. In general, there is great potential to reduce weed infestation in arable fields by HWSC (Akhter et al., 2023; Bitarafan, Andreasen, 2020a; 2020b; 2020c; Walsh et al., 2018).

Chaff is a by-product of grain harvest comprises weed seeds and husk. Collected chaff can be moved into a bulk bin attached to a combine harvester by a transfer mechanism that delivers the chaff containing weed seeds. The chaff can then be removed from the field and used as a new biomass feedstock (Glasner et al., 2018). Chaff can be utilized as a renewable energy feedstock, material for construction (*e.g.*, insulating boards, cardboard, bedding), soil improvement (*e.g.*, mulch, mushroom compost), and for agricultural purposes (*e.g.*, weed growth inhibitor, animal diet). However, chaff has a low bulk density, making it troublesome to handle and store as it takes up a large space. Therefore, compressing chaff into pellets improves its handling and reduces the storage area.

Transportation and use of pelletized chaff containing weed seeds may pose a risk of spreading problematic plant species, including herbicide-resistant genotypes of weeds or invasive plant species. Therefore, it is important to investigate whether

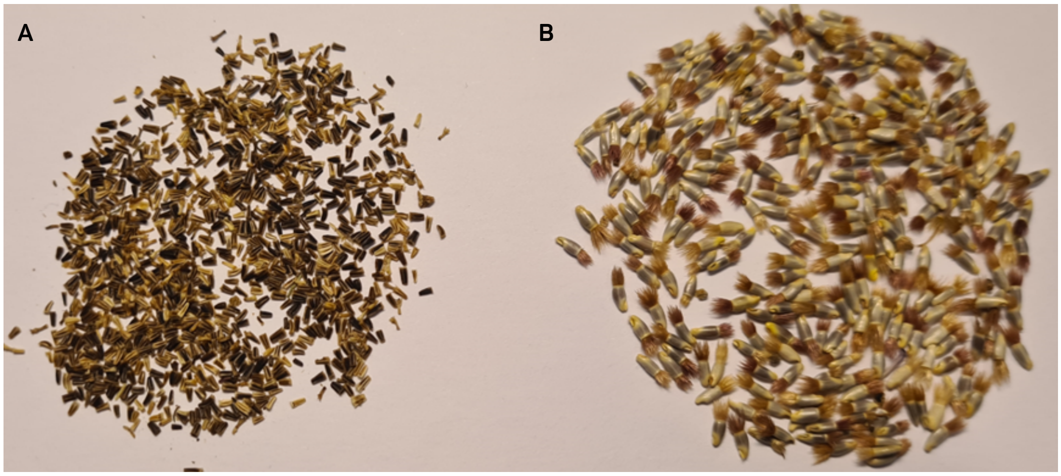

Figure 1 - a. Seeds of scentless mayweed (*Tripleurospermum inodorum*) and b. cornflower (*Centaurea cyanus*)

pelletized chaff poses a risk of spreading weed seeds. We studied two types of pelletized chaff supplied with weed seeds of the two species scentless mayweed (*T. inodorum*) and cornflower (*C. cyanus*) to test whether the seeds in the pellets were able to germinate after water uptake. The weeds species were chosen because they have different seed size and weight and a relative high germination percentage. *Tripleurospermun inodorum* is a common weed in Europe while C. *cyanus* is less widespread (Andreasen, Stryhn, 2012; Kraehmer et al., 2020). In this study, we examined two types of pelletizing chaff containing weed seeds to determine whether the seeds in pellets were able to germinate after water uptake.

2. Material and Methods

2.1 Chaff and Weed Seeds

Chaff was collected from a winter wheat field that was harvested by the company Claas Selbstfahrende Erntemaschinen GmbH, in Germany, and then sealed before storage. The chaff had a bulk density of 34 g L^{-1} and consisted mainly of husks with a mean length of 0.8 cm and straw with a length of 1–20 cm.

Original wheat chaff and fine wheat chaff which was pretreated by sieving (see 2.2 Pelletizing of Chaff) were mixed with seeds of the weed species scentless mayweed (*T. inodorum*) and cornflower (*C. cyanus*), respectively. They were chosen due to their different seed sizes, weights and relatively good germination ability. The mean size and weight were 2.3 mm × 1.0 mm and 0.4 mg for scentless mayweed, and 3.7 mm × 1.8 mm and 4.5 mg for cornflower (Figure 1). The seeds were collected from fields at the research station of the University of Copenhagen in Taastrup (55°38´N, 12°17´E), Denmark, dried, and stored at 5 °C.

Based on weight, approximately 2,000 seeds of each weed species were added to 2,500 g of chaff (20% moisture). 5 × 100 seeds were weighed (*T. inodorum*: 100-seed weight = 0.03386 g (SD = 0.00112 g); *C. cyanus*: 100-seed weight = 0.3407 g (SD= 0.1374 g). The treatment was replicated four times.

2.2 Pelletizing of Chaff

The pelletizing process was carried out at Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT, Germany. The pelleting press used was an Amandus Kahl pelleting press, type 14-175 (Amandus Kahl GmbH & Co. KG, Dieselstrasse 5–9, 21465 Reinbek, Germany) as shown in Figure 2. The die had a bore diameter of 6 mm and a length of 30 mm.

The temperature at the outer side of the die was monitored with a thermocouple. The press was manually fed from the top and produced pellets were collected on a vibrating sieve with a mesh size of 4 mm and a total length of 1.3 m.

As pre-treatment, the wheat chaff was initially subjected to sieving using a drum screen. The sieve holes in the first half of the drum screen were circular, with a diameter of 8 mm, while the sieve holes in the second half were elongated with a length of 21 mm and a width of 8 mm. This pre-sieving process resulted in the sorting out of 20% (w/w) of the original chaff fraction, which consisted mainly of straws. The fine fraction, which primarily comprised small thin straws of up to 5 cm in length and husks, had a bulk density of 50 g L^{-1}.

The pelletizing experiments were conducted using both the original chaff and the fine fraction. The fine chaff fraction did not require any milling. Starch was used as a binder and mixed with dry material and water to achieve the intended initial water content (20%) for the pelletizing experiments. The ingredients were mixed in a conventional

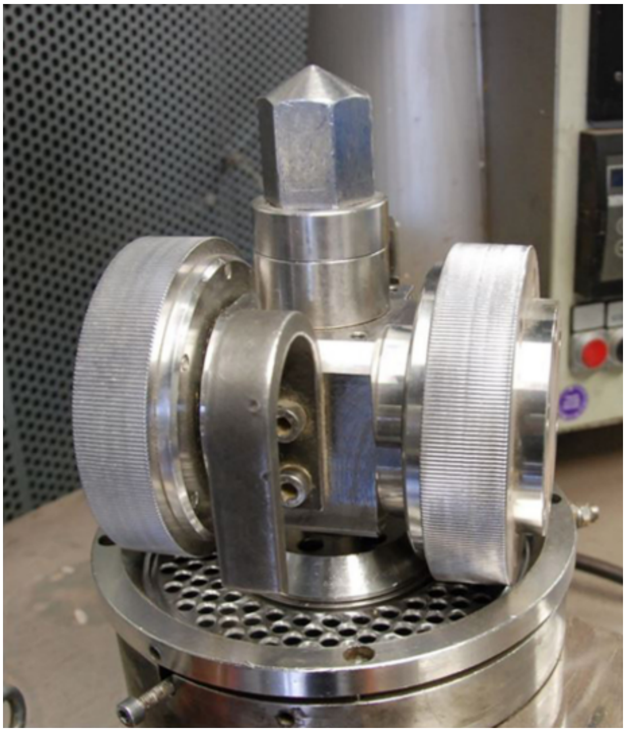

Figure 2 - Amandus Kahl pelleting press, type 14-175 (Amandus Kahl GmbH & Co. KG, Dieselstrasse 5–9, 21465 Reinbek, Germany) (modified after Weiss and Glasner [2018])

cement mixer for at least 20 min. Before each treatment, the die was preheated until the thermocouple on the outer side of the die registered a temperature above 50 °C to obtain the glass transition temperature of the straw (between 53 and 63 °C) (Whittaker, Shield, 2017). The die was preheated by adding pre-ground material to the running pellet press until the selected temperature was reached, where after the feed was switched to the desired feedstock. After 5–10 min, the pellets were collected, ensuring that the initial material was completely flushed out. Then the pellets were cooled down at room temperature, stored in a sealed box and sent to the University of Copenhagen, Denmark, to be tested for seed germination. A detailed description of the pelleting apparatus and procedure has been published by Weiss and Glasner (2018).

2.3 Germination Experiment

Pelletized samples were spread evenly on the peat soil surface (Pindstup mixture 2) (Pindstrup mosebrug, Ryomgaard, Denmark), in 14 × 16 cm boxes (Figure 3a) and covered with a thin layer of sand. Unpelletized chaff samples were used as controls. The boxes were placed in a greenhouse (mean temperature 20 °C) and watered from the bottom. Natural light were supplemented with artificial light from HPS SON-T 400 W lamps 16 hours day^{-1}. Seed germination was recorded over the

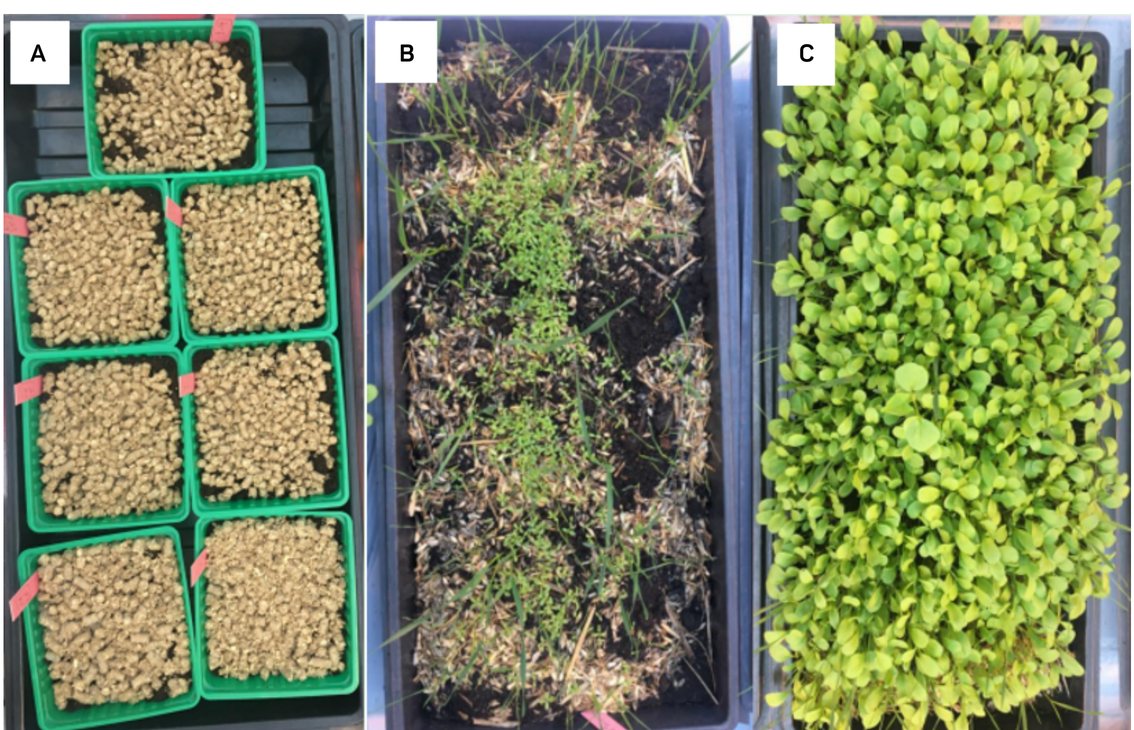

Figure 3 - a. Boxes with pelletized chaff containing weeds seeds. b. Germinating seeds from unpelletized chaff samples containing weed seeds from the field (*e.g.*, grasses) and added scentless mayweed (*T. inodorum*) seeds. c. Germinating seeds from unpelletized chaff samples containing weed seeds from the field and added cornflower (*C. cyanus*) seeds

course of one month (2 Februar 2019 to 3 March 2019). The seedlings was counted and removed every week. No seedlings emerged in the last week.

3. Statistical analyses

The germination percentage was compared between the control group and the seeds from the pelletized chaff using a logistic regression. Standard errors (SE) of the germination percentages were estimated.

4. Results and Discussion

In all four replicates, no weed seeds germinated in pelletized original and fine wheat chaff samples (SE = 0) (Figure 3a). In contrast, in the controls, 22% (SE = 9.8) and 59% (SE = 8.6) of *T. inodorum* and *C. cyanus* seeds germinated in wheat chaff samples, respectively (Figure 3b, c). Hence, the germination percentage of seeds in the control group were significantly higher than the seeds from the pelletized chaff ($p < 0.0001$).

The results indicate that the pelletizing process probably destroyed the germinability of weed seeds in the pellets. Therefore, we do not expect any risks of spreading weed seeds with chaff pellets, for example, during transport or storage.

The compression of the seeds during the pelletizing process may caused crushing or physical damage. Additionally, the temperature required to reach the glass transition temperature of straw, which ranges from 53 to 63 °C (Whittaker, Shield, 2017) could have harmed the seeds. For many plant species, high germinability of dry seeds is best maintained at low temperatures and declines at increasing temperatures (Solberg et al., 2020).

The weed seeds may have absorbed moisture from the chaff during the pelletizing process, which could have made them even more susceptible to heat damage. When most imbibed seeds are exposed for temperatures exceeding 40–43°C, essential enzymes start to degrade, negatively affecting the seeds' germinability (Vegis, 1963).

We cannot exclude the possibility that the pelletizing process could have induced seed dormancy in some seeds because we did not test seed germination from the pellets after storage at low temperatures for a more extended period to release dormancy. Neither did we conduct any other kind of treatments to release eventual seed dormancy.

The results revealed that the success of pelletizing was highly dependent on the water content of the feed, underscoring the importance of precise conditioning (Weiss, Glasner, 2018). Pre-sieving the chaff was found to be beneficial for enhancing its handling properties, as evidenced by the analysis of presorted and original chaff samples.

5. Conclusions

None of the weed seeds germinated in pelletized original and fine wheat chaff samples, while 22% and 59% of *T. inodorum* and *C. cyanus* seeds germinated in wheat chaff samples (the controls), respectively. The results indicated that the pelletizing process probably destroyed the germinability of the weed seeds in the pellets.

However, given that no experiment was conducted to test for seed dormancy induced by the pelletizing process, it remains possible that some seeds may have become dormant, which need to be studied in the future.

Other weeds may react differently on the pelletizing process. Therefore, the effect of the pelletizing process on other species should be studied, for example, heat tolerant species like *Portulaca oleracea* L. and *Amaranthus retroflexus* L. and grass species (*e.g.*, *Sorghum halepense* (L.) Pers.) (Egley, 2017).

Compressing chaff into pellets improves its handling and reduces the storage area, and our preliminary results indicate that the pelletizing process kill the weed seeds in the chaff.

Consequently, our results did not identify any significant risk of spreading weed seeds with pelletized chaff, even if it is spilt or left on the soil during transport and storage.

Conflict of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study, the collection, analyses, interpretation of data, the writing of the manuscript or in the decision to publish the results.

Author's contributions

CG, ZB, and CA: conceptualization of the manuscript and development of the methodology. ZB: data collection and curation. ZB: data analysis. CG, ZB, and CA: data interpretation. CG and CA: funding acquisition and resources. CG and CA: project administration. CA: supervision. CA: writing the original draft of the manuscript. ZB, CG, and CA: writing, review and editing. All authors read and agreed to the published version of the manuscript.

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