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Investigating Dried Distiller's Grains with Solubles vulnerability to *Tribolium castaneum* (Herbst) infestation by using choice and no-choice experiments

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ABSTRACT

Demand for Dried Distiller's Grains with Solubles (DDGS) in international markets and the United States has increased during the past few years. Knowledge of DDGS supplemented animal feed vulnerability to insect infestation is critical for safe feed storage. To assess this vulnerability, it is necessary to know how DDGS is susceptible to insect infestation, while stored as raw ingredient. This research focused on the susceptibility of different types of DDGS (raw and ground) to red flour beetle, *T. castaneum*, infestation under 30% and 50% relative humidity (r.h.) regimes. Larval period at 30% r.h. increased 2–3 fold on raw DDGS diets with larger particle sizes (PSs) compared with their normal laboratory diet, a mixture of flour and yeast (9:1) (F/Y). However, grinding DDGS samples and increasing the r.h. to 50% decreased the amount of time required for insect development thus increasing DDGS vulnerability to *T. castaneum* infestation compared with raw DDGS at r.h. of 30%. As was expected, *T. castaneum* egg and pupal development were not affected by diet or humidity. The results suggested that DDGS as a raw ingredient at 30% r.h. was not a suitable food source for *T. castaneum* and given a choice, the majority of *T. castaneum* adults prefer laboratory diet over DDGS. Additionally, fecundity was significantly lower on DDGS compared with the control diets (F/Y and ground corn (GCORN)). These results indicated that these types of DDGS were not suitable developmental diets compared with the F/Y diet if stored at 30% r.h. with larger PSs.

1. Introduction

Dried Distiller's Grains with Solubles (DDGS), a co-product of the ethanol-production process, has a high nutritional content and is used in animal feed as a substitute for corn or other grains (Rosentrater, 2007; Kingsly and Ileleji, 2009; Kingsly et al., 2010). After sugar in the grain (such as corn) is fermented into ethanol, the remaining un-fermentable residues are separated into two parts - liquids and insoluble solids. Liquids are further condensed by using an evaporator, and are known as condensed distiller's solubles (CDS), while the insoluble solids are known as distiller's wet grains (DWG). DDGS is produced by blending CDS and DWG and is then dried to reach the final moisture content (m.c.) of 10–13% (Rosentrater, 2006; Kingsly et al., 2010). DDGS contains protein, fiber, oil, and ash in concentrations approximately 2–3 times higher than raw grain (Shurson et al., 2003). In the United States, more than 200 ethanol plants, primarily in Northern and Mid-western states, have the capacity to produce more than 53 billion l of ethanol and 30 billion kg of DDGS (U.S. Grains Council, 2015). In 2014 more than 10 billion kg of DDGS was exported to more than 45 countries. China, Mexico, South Korea, Vietnam, and Japan were the top 5 countries (U.S. Grains Council, 2015).

Most Distiller's Grains (DG) have been used primarily in cattle feed followed by feeds for swine and poultry (RFA, 2014). Prior to use, DDGS presents several challenges during storage. Some common challenges when storing and transporting DDGS are caking, bridging, low flowability (Ganesan et al., 2008), and insect infestation. However, insect infestation in DDGS has not been thoroughly investigated and currently studies of DDGS susceptibility to insect infestation are limited. Understanding the effect DDGS might have on the vulnerability of animal feed to insect infestation is

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essential. To answer this question, first susceptibility of DDGS as raw ingredient to insect infestation should be investigated to establish the best conditions preventing insect infestation in stored DDGS.

Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) as one of the most common insect pests of stored-products (Arbogast, 1991; Ahmad et al., 2012) originally came from India, southwestern Asia, and eastern Mediterranean (Good, 1936). Food, temperature, and humidity are important factors influencing *T. castaneum*'s life cycle (Good, 1936). *T. castaneum* has been reported to feed on a wide variety of products including flour, meals, cereals, animal matter, wood, dried fruit, vegetables, drugs, damaged seeds, cracked nuts, as well as whole-wheat flour which has a higher risk of being infested by this insect (Good, 1936). Therefore, *T. castaneum* seems an ideal insect pest to evaluate DDGS susceptibility to infestation by secondary feeders. This research is based on a study by Fardisi et al. (2013) on the susceptibility of two DDGS samples, which were obtained from an "old" generation dry-grind fuel-ethanol process plant. Both DDGS samples were found as an unsuitable diet for *T. castaneum* at 32.5 °C (Fardisi et al., 2013). Studies by others showed that chemical (Cromwell et al., 1993; Shurson et al., 2003; Kingsly et al., 2010) and physical properties of DDGS vary from each production facility (Rosentrater, 2006). As different production procedures affect the final quality of DDGS products (Ganesan et al., 2006, 2008; Kingsly et al., 2010). For example PS is different among DDGS samples (Kingsly et al., 2010) and seems to be an important factor in susceptibility of DDGS to *T. castaneum* infestation (Fardisi et al., 2013). Thus, the main objective of this study was to examine the vulnerability of different types of DDGS to *T. castaneum* infestation by conducting two experiments. The first experiment determined *T. castaneum* developmental time at two r.h. regimes (30% and 50% r.h.) and their number of successful fecundity at 30% r.h. on DDGS diets in contrast with a standard laboratory diet by using no-choice experiments. Optimal r.h. for *T. castaneum* growth is 70% (Howe, 1956; Arbogast, 1991), but for safe storage of DDGS at 20–30 °C, r.h. should be < 50–60% (Kingsly and Ileleji, 2009). Therefore, 30% and 50% r.h. regimes were chosen because at 30% r.h., environmental conditions suppress insect growth while remaining suitable for DDGS storage. While at 50% r.h. favorable growth conditions are provided for *T. castaneum*, and it is within the highest r.h. range recommended for DDGS storage. The second experiment investigated *T. castaneum* adult food preference by using choice experiments when insects were free to choose their food. This information helped us in better understanding the vulnerability of various types of DDGS to *T. castaneum* infestation in the storage.

2. Materials and methods

2.1. Insect and diet preparation

T. castaneum were obtained from two cultures. The first was a laboratory colony which was maintained on a diet of wheat flour and brewer's yeast (9:1) (F/Y) in I-36 series environmentally-controlled chambers (Percival Scientific Perry, IA 50220, USA) at 27 °C (±1) and 30% r.h. in the Department of Entomology at Purdue University, West Lafayette, IN, USA. To insure that developmental results on DDGS diets were not due to habituation to a F/Y diet another *T. castaneum* culture was reared on a DDGS diet. The second culture was made by the following procedure: Six hundred randomly selected *T. castaneum* adults were allowed to oviposit in 3 glass jars (24 oz = ~710 ml Mason jar) (200 insects per jar); half-filled with the mixture of raw and ground (1:1) DDGS sample called P_3–B_1. Designation P_3–B_1 refers to Plant 3-Batch 1 (Fig. 1). This colony was kept at 32.5 °C ± 1.0 °C and 50% r.h. in environmentally-controlled chambers. After 2 d, adults were removed from jars. *T. castaneum* colonies on DDGS diet were maintained by adding adults which were reared on a P_3–B_1 diet, to fresh P_3–B_1 diet jars once a month.

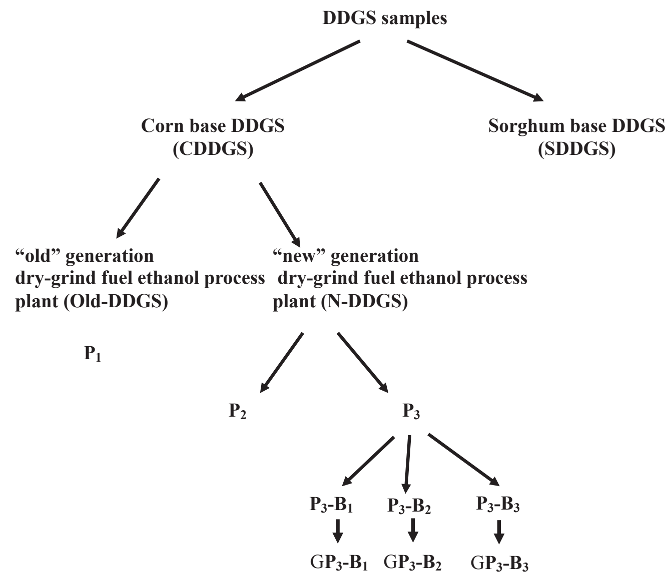

Fig. 1. Category of DDGS samples tested to determine their susceptibility to *Tribolium castaneum* infestation. Dried Distiller's Grains with Solubles (DDGS) were DDGS corn-base included plant 1 (P_1), plant 2 (P_2), plant 3 batch 1 (P_3–B_1), plant 3 batch 2 (P_3–B_2), plant 3 batch 3 (P_3–B_3), ground plant 3 batch 1 (GP_3-B_1), ground plant 3 batch 2 (GP_3-B_2), ground plant 3 batch 3 (GP_3-B_3), DDGS sorghum-base (SDDGS).

Six samples of DDGS were tested in this study including: five samples made of corn (CDDGS) and one sample made of sorghum (SDDGS) (Fig. 1). Normal laboratory diet (F/Y) and ground corn (GCORN) were also used as control diets for comparison with DDGS samples. GCORN was chosen as a second control diet, since most of DDGS samples were corn-based. Diets were kept refrigerated at 4 °C for longer preservation for the whole period of study. Diets were kept 2 d at the room temperature and were re-blended with a spoon to mix segregated particles before being used in experiments. DDGS samples included:

1. CDDGS sample #1 was labeled as Plant 1 (P_1) and it was obtained from an "old" generation dry-grind fuel-ethanol process plant. An "old" generation is defined as a plant, constructed in the early 1980s compared with "new" generation dry-grind fuel-ethanol process plant, built after 1990 (Ileleji et al., 2007). This sample was prepared and dried in Indiana, USA.
2. CDDGS samples #2–5 were obtained from two "new" generation dry-grind fuel-ethanol process plants. Sample #2 was labeled as Plant 2 (P_2). The rest of samples from #3 to #5 were labeled as Plant 3 (P_3). P_2 and P_3 samples were prepared in Indiana, USA but at two different plant facilities. Plant 3 samples were produced by mixing different concentration of CDS with DWG according to Kingsly et al. (2010) as summarized below:
   1. 212 l/min CDS (7.4% of total inflow by volume) (Batch 1) (P_3–B_1)
   2. 98.4 l/min CDS (3.7% of total inflow by volume) (Batch 2) (P_3–B_2)
   3. 0 l/min CDS (0% of total inflow) (Batch 3) (P_3–B_3)
3. SDDGS was made of pure sorghum in Arizona, USA (Fig. 1). DDGS diets contained bigger and inconsistence PSs compared with F/Y diet which had fine PS. Therefore, ground samples of the P_3–B_1, P_3–B_2, and P_3–B_3 (GP_3-B_1, GP_3-B_2, and GP_3-B_3) were also provided using a Udy cyclone mill (UDY Corporation, Fort Collins, CO).