THESIS

STEM SOLIDNESS AND LITTER QUALITY IMPACTS ON RESIDUE DECOMPOSITION AND RESIDUE COVER IN DRYLAND WINTER WHEAT

Submitted by

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ABSTRACT

STEM SOLIDNESS AND LITTER QUALITY IMPACTS ON RESIDUE DECOMPOSITION AND RESIDUE COVER IN DRYLAND WINTER WHEAT

Solid-stem wheat varieties have been widely adopted across the Great Plains as a management strategy for wheat stem sawfly (*Cephus cinctus,* Norton), yet their consequences for post-harvest residue decomposition and soil cover persistence remain poorly understood. This study evaluated whether stem solidness influences residue decomposition and residue cover persistence across a gradient of eight winter wheat varieties ranging from hollow to semi-solid, using a 134-day laboratory incubation, a 229-day field litterbag experiment, and residue cover monitoring across three site-years under dryland winter wheat production in Colorado. Neither laboratory-measured nor commercial solidness ratings significantly predicted decomposition responses in either study. Instead, fiber fractions, particularly amylase treated neutral detergent fiber (aNDF), acid detergent fiber (ADF), and hemicellulose, along with nitrogen (N) availability, indicated by total N and C:N ratio, were the dominant predictors of cumulative C mineralized, decay rate, final C remaining, and final mass remaining across both studies. In the litterbag study, variety-level differences in residue persistence were driven primarily by differences in early mass loss rather than overall decay rates. The relative ranking of varieties was consistent across the incubation and litterbag environments despite large differences in overall decomposition rate, suggesting that residue chemical composition is a robust driver of decomposition dynamics independent of environmental setting. Lignin-based indices were

comparatively weak predictors, as was expected with the early decomposition stage captured here, where decomposition did not exceed the threshold at which lignin typically becomes the dominant control on decay rate. Residue cover across three site-years showed high stem solidness plots (solidness ratings 16,19) maintained significantly greater cover than medium solidness plots (solidness 10). Together, these findings indicate that fiber content and N availability are more reliable predictors of residue decomposition outcomes in dryland wheat systems than stem solidness, and that growers selecting solid-stem varieties for sawfly resistance need not expect large or consistent residue cover impacts from that selection.

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1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is among the most widely cultivated crops in the world, accounting for 41% of global cereal calorie intake and approximately one-fifth of total daily calories and protein consumed worldwide (Shiferaw et al., 2013). In North America, the Great Plains region represents the center of winter wheat production, accounting for the majority of U.S. and Canadian output (USDA ERS, 2024; Statistics Canada, 2024). Within this region, Colorado's eastern plains represent a significant production area, with producers seeding approximately 2.3 million acres of winter wheat annually, generating an estimated $522 million in crop value and ranking among the state's leading agricultural commodities (USDA NASS, 2024). Like much of the Great Plains, however, dryland wheat production in Colorado faces growing challenges from a range of biotic and abiotic stressors that can substantially reduce yield and grain quality.

Among insect pests, the wheat stem sawfly (WSS; *Cephus cinctus,* Norton) has emerged as one of the most economically significant threats to wheat production across the Great Plains. WSS is distributed broadly across dryland wheat-producing regions of the Great Plains (Lesieur et al., 2016), where it has been estimated to cause yield losses exceeding 30% and economic losses of $350 million annually across the northern Great Plains and Canadian prairies (Beres et al., 2011). In recent decades, WSS has expanded southward into Colorado, where yield losses of 20–50% and annual economic losses of $40 million were reported in 2022 alone (Peirce et al., 2024). The total economic impact of yield losses due to WSS average approximately $70 million per year over the 2019–2022 period (Wasserman-Olin et al. 2024).

Damage from WSS is primarily driven by larval activity within the stem. In spring to early summer, females oviposit eggs in maturing wheat stems, with a preference for larger stems

(Beres et al., 2011; Cárcamo et al., 2005; Vieira et al., 2025), and larvae feed internally throughout the growing season, reducing grain weight (Delaney et al., 2010). As plant moisture declines and light penetration through the stem wall increases later in the season, larvae migrate to the base of the stem, cutting it in preparation for overwintering (Holmes, 1975). This activity weakens the stem and increases susceptibility to lodging, which further reduces harvestable yield (Beres et al., 2012; Delaney et al., 2010).

In response to the spread of WSS, wheat breeders have developed solid-stem varieties as a primary management strategy (Peirce et al., 2022; Bathini et al., 2023). In most wheat varieties, the stem internode contains a central hollow cavity enclosed within a thin-walled cylinder of vascular and structural tissue (Bathini et al., 2023). In solid-stem varieties, this cavity is filled during stem elongation with parenchymatous pith, with living cells that store water-soluble carbohydrates throughout the growing season, which are subsequently transported to the grain head to support grain fill (Bathini et al., 2023; Saint Pierre et al., 2010). This pith tissue physically impedes WSS larval movement and survival (Holmes & Peterson, 1961, 1962). The degree to which the cavity is filled varies across varieties and is quantified as the proportion of the internode cross-section occupied by pith, ranging from fully hollow to fully solid (DePauw & Read, 1982). It should be noted that expression of the solidness trait is sensitive to environmental conditions during stem elongation, with reduced pith expression associated with low light intensity (Holmes, 1984), high precipitation (Nilsen et al., 2016; Subedi et al., 2021), cool temperatures (Hayat et al., 1995), and higher seeding densities (Beres et al., 2012).

While solid-stem varieties have been widely adopted as a management tool, the implications of this shift extend beyond pest resistance. In semiarid environments where precipitation is limited and soils are prone to wind and water erosion, residue cover provides

critical protection against soil loss (Schnarr et al., 2022; Peterson et al., 2020), moderates soil temperature (Goettl et al., 2025), and conserves moisture by reducing evaporative demand (Van Donk et al., 2010). As one of the most widely grown crops in the Great Plains, winter wheat is critical for the management of soil cover in dryland cropping systems (Hansen et al., 2012; Blanco-Canqui & Wortmann, 2017). Wheat produces high residue biomass that decomposes slowly relative to legume and many broadleaf residues, owing to its high C:N ratio and lignin content, allowing it to persist as soil cover to significant periods. Wheat residue cover on the soil surface is therefore a management-relevant outcome with direct implications for soil health and long-term productivity.

Residue cover is largely determined by decomposition dynamics which in turn are governed by the interaction of climate, soil biological activity, and residue quality (Johnson et al., 2007). Residue quality has received considerable attention as a predictor of decomposition dynamics across environments. For example, nitrogen (N) content has long been shown to be an important driver of decomposition, as residues with low N concentrations relative to carbon (C) create conditions of microbial N limitation that slow decomposition (Henriksen & Breland 1999). High fiber content, including lignin, cellulose, and hemicellulose, also impedes decomposition, as the lignocellulosic matrix formed by their physical and chemical association resists microbial colonization and enzymatic breakdown (Berg & McClaugherty, 2014). Lignin and lignin-based indices such as the lignin:N ratio and the lignocellulose index are correlated with residue decomposition rates (Talbot & Treseder, 2012; Moorhead et al., 2013), with lignin exerting stronger control as labile fractions are preferentially consumed and N becomes limiting (Henriksen & Breland, 1999; Gao et al., 2016). Because residue decomposition directly governs

the rate at which surface cover is lost, the chemical and structural composition of crop residue is a key control on how long cover persists at the field scale.

Stem solidness in wheat is expressed along a continuum rather than as a discrete trait and is commonly rated on a scale of pith development ranging from hollow to fully solid (DePauw & Read, 1982; Sherman et al., 2010). Most sawfly-resistant varieties fall between these extremes, exhibiting semi-solid expression rather than stems fully filled with pith. As these solid- and semi-solid-stemmed varieties become more widely planted across the Great Plains, large quantities of chemically and structurally distinct residues are returned to the soil surface at harvest each year. Solid-stem varieties contain a greater proportion of pith tissue relative to total stem cross-sectional area than hollow-stem varieties, and this pith is chemically distinct from the surrounding stem wall. Pith parenchyma is cellulose dominated with relatively low lignin and high concentrations of water-soluble carbohydrates (Ford et al., 1979; Saint Pierre et al., 2010; Scofield et al., 2009), while the outer stem wall tissue is heavily lignified (Bisht et al., 2022). Whether these differences in hollow and solid stem litter quality translate into meaningful differences in decomposition rates and soil cover persistence under field conditions, however, has yet to be formally evaluated.

Given the importance of wheat residues for maintaining soil cover and the uncertainties related to how solid-stem varieties might influence residue dynamics, there is a need for further study on how stem solidness influences wheat residue decomposition and soil cover persistence in dryland cropping systems. Therefore, the objective of this study was to evaluate the extent to which the solid stem trait versus other residue quality metrics influence residue decomposition rates and persistence across a gradient of stem solidness. We hypothesized that stem solidness would negatively affect decomposition rates across varieties, with more solid stems decomposing

more slowly due to their greater physical density and structural complexity. We further hypothesized that slower decomposition rates in solid-stem varieties would translate into greater residue cover persistence at the field scale relative to hollow-stem varieties. Better understanding of these dynamics will help inform variety selection and residue management in dryland wheat systems, where residue cover is critical for soil water conservation, erosion control, and long-term productivity.

2. MATERIALS AND METHODS

2.1. Study Approach

To understand the influence of stem solidness and residue chemical quality on decomposition dynamics, we conducted a laboratory incubation study under controlled temperature and humidity conditions, isolating the effect of residue quality from environmental variability, and a field litterbag study to capture decomposition under ambient climate conditions relevant to dryland management. Residue cover, silhouette area index, and WSS infestation were also monitored to assess whether variety-level differences in decomposition translate into detectable field-scale outcomes and to account for the potential independent influence of stem structural damage on residue chemistry. Eight winter wheat (*Triticum aestivum*) varieties (Byrd CL Plus, Canvas, AP Solid, WB4444, Fortify SF, Amplify SF, Windom SF, and WB4733) were selected to represent a gradient of stem solidness (Table 1). Wheat straw for all eight varieties was collected immediately after harvest on July 10, 2025, at the Colorado State University (CSU) Agricultural Research, Development, and Education Center (ARDEC) in Fort Collins and returned to the lab for air-drying.

2.2. Residue Quality Analysis

In the lab, solidness was assessed by dissecting five stem internodes per plant and visually scoring the proportion of the cross-section occupied by pith on a scale of 1 to 5 per internode, with scores summed to produce a composite solidness rating ranging from 5 to 25 (DePauw & Read, 1982; Sherman et al., 2010). Ratings across the eight varieties ranged from hollow (solidness = 5) to semi-solid (solidness = 19). Sub-samples of each variety were also sent to the CSU Soil, Plant, and Water Testing Laboratory for analysis of total C and N via dry combustion, using an elemental analyzer (Tiessen et al., 1981; Sheldrick, 1986). Acid detergent fiber (ADF), amylase-treated neutral detergent fiber (aNDF), lignin, cellulose, and hemicellulose were determined using sequential fiber analysis conducted on an ANKOM A2000 fiber analyzer using the filter bag technique (Undersander et al., 1993), with samples ground to pass through a 1 mm screen prior to analysis. Cellulose was calculated as the difference between ADF and lignin, and hemicellulose as the difference between aNDF and ADF.

2.3. Incubation Study

For the residue incubation experiment, the eight wheat varieties (Table 1) were incubated in air-tight glass jars (950 ml) with rubber septa in the lid to allow for gas sampling with a syringe. The residues were incubated with soil collected near Akron, Colorado (see site info for litterbag experiment below) to provide a more active microbial community and better regulate temperature and moisture in the jars. Soil (0–10 cm) was collected in August 2025 at the field site and immediately returned to the lab to be air-dried, sieved to 2 mm, and homogenized. Specimen cups (120 ml) were placed at the bottom of each jar with 15.0 ± 0.5 g of soil filling the base of each cup. Soil moisture was standardized by rewetting to 70% of water holding capacity by adding 7.0 ml deionized water, using a pipette. Air-dried wheat stems of each variety were cut

into ~2 cm segments and homogenized thoroughly. Then 2.5 g of residue was placed on top of the rewetted soil in the specimen cups within each jar. Deionized water (30 ml) was added to the bottom of each jar, underneath the specimen cup to maintain humidity. Each variety was replicated eight times, for a total of 64 jars containing wheat residue. To quantify background soil respiration, five additional jars containing only moistened soil were incubated to understand soil vs. residue contributions to CO_2 mineralization.

All jars were placed in a dark room and maintained at a constant temperature of 25℃ for a total incubation time of 134 days. Concentration of CO_2 was monitored every 1-3 days (daily at the start of the incubation and then less frequently as decomposition slowed) by mixing the headspace of each sealed jar using a syringe, then extracting a 2.0 ml atmosphere sample and immediately injecting it into a LiCor LI-820 CO_2 gas analyzer. Jars were opened and flushed with ambient air after each CO_2 measurement to maintain CO_2 concentrations below 2% and then resealed for continued CO_2 accumulation. Cumulative C respired was calculated as the sum of daily C fluxes (mg C) per replicate, and percent C remaining was calculated as the proportion of initial C remaining after subtracting cumulative C respired.

2.4. Litterbag Study

The litterbag study was conducted at the USDA-ARS Central Great Plains Research Station near Akron, Colorado (40.15, -103.14). With an elevation of 1384 m, the climate is semi-arid with dry, cold winters and hot summers. The mean annual precipitation is 420 mm with most falling between April and August. The mean monthly minimum and maximum temperatures range from 15°C to 31°C in July to -9°C to 3.5°C in January. The topography is generally flat, with slopes less than 3 %. Soils in this area include Weld silt loam (fine, smectic,

mesic Aridic Argiustolls) and Rago silt loam (fine, smectic, mesic Pachic Argiustolls) (Noble Strohm et al., 2025).

Wheat stem residues from seven of the eight varieties mentioned above (Table 1), were cut into long 5-8 cm segments and 2.5 ± 0.1 g of this material was placed into litterbags (20 × 12 cm), constructed out of ~1 mm stainless steel mesh. A sub-sample of each variety was oven-dried at 60 °C prior to field placement to determine initial moisture content of air-dried residues. The litterbags were stapled shut and placed in the field on August 25, 2025, in a recently harvested dryland wheat field at the USDA - ARS Central Great Plains Research Station.

Litterbags were carefully placed within a layer of existing wheat residues, ~1 cm above the soil surface. Litterbags were retrieved 33, 70, 98, 174, and 229 days after placement, with six replicates collected on each sampling date for each variety. Upon collection, litterbags were immediately returned to the laboratory, opened, and the remaining residues were gently cleaned to remove debris. Samples were then dried at 60 °C and weighed to determine the remaining mass.

2.5. Residue Cover Monitoring

Residue cover was assessed within existing dryland wheat variety trials across three site-years in Colorado, an experimental field adjacent to the Akron USDA-ARS site in 2025, the Akron USDA-ARS site in 2026, and a site near Yuma in 2026. For each site-year, plots representing low, medium, and high solidness classes were sampled, with three replicates per solidness class. Because the field plots used different plant material than the incubation and litterbag studies, varieties were classified using their commercial solidness ratings, breeder-assigned values on the standard 25-point scale (5 = hollow to 25 = fully solid) under which each variety is marketed. Low solidness plots were represented by Canvas and Langin (rating 5),

medium by Fortify SF (rating 12), and high by AP Solid and WB4733 (ratings 17 and 19, respectively) In each plot, a quadrat (50 × 50 cm) was placed at three representative locations and percent cover of residue, soil, and weeds were visually estimated. Stem density was quantified by counting stems along three representative 50 cm row sections per plot. Within each section, stem diameter was measured with calipers on five randomly selected stems and height on eight randomly selected stems. Mean stem density, diameter, and height were then combined to calculate the silhouette area index (SAI) for each plot (Bilbro and Fryrear, 1994). Together, these site-years allowed residue cover to be compared across solidness classes with site-year as a blocking factor, providing a broader environmental context for interpreting variety-level differences in residue persistence.

$$\text{SAI} = \text{Stem Density} \times \text{Height} \times \text{Diameter}$$

On the final sampling date at Akron (April 11, 2026), biomass was collected from one quadrat per replicate plot by cutting stems approximately 1 cm above the soil surface and collecting all litter from the soil surface. Once in the lab, samples were gently cleaned to remove soil, dried at 60°C until reaching a constant mass, and weighed.

WSS infestation was assessed by collecting three bundles of stems from each plot in Akron on February 22 and April 11, 2026, and recording the proportion of stems showing larval activity. Stems were transported to the laboratory and stored frozen until processing. Each stem was dissected longitudinally using a scalpel and examined for evidence of WSS activity, including larvae, frass, and the cocoons of *Bracon cephi* and *B. lissogaster*, native braconid wasps that parasitize WSS larvae and whose cocoons indicate prior WSS occupancy (Runyon et

al., 2002). A stem was classified as infested if any of these indicators were present, and infestation rate was calculated as the proportion of infested stems within each plot.

2.6. Data Processing

In the incubation study, full-trajectory decay rates (considering all 134 days) were estimated for each jar individually by regressing the natural log of percent C remaining against time, yielding a single decay rate per jar. Full-trajectory slopes did not always provide a good fit because of a transition between rapid early loss and a slower later phase at approximately 10 days (Fig. 1). Phase-specific decay rates were therefore also estimated by defining an early phase (day 0–10) and a late phase (day 10–134), with the breakpoint corresponding to the transition from rapid initial C loss to a slower phase. For each phase, slopes were estimated separately for each jar, yielding eight slope estimates per variety. These jar-level decay rates served as the unit of replication in subsequent ANOVA, and variety-level means of these slopes were used as the response variable in regression against residue quality metrics to avoid pseudoreplication.

In the litterbag study, variety-level decay rates and intercepts were estimated using multiple linear regression of the natural log of mass remaining as a function of time, variety, and their interaction fit across all bags and timepoints, yielding a single slope and y-intercept per variety. When rapid initial mass loss from leaching of soluble fractions is substantial, constraining the model through zero (100% mass remaining) can produce poor fit and conflate leaching losses with microbial decomposition, so a free intercept term was allowed in the model, serving as a variety-level proxy for initial leaching losses (Fonte & Schowalter, 2004). The significance of the variety × time interaction term was used to test whether decay rates differed among varieties. These variety-level slopes and intercepts were used as response variables in

subsequent regressions against solidness ratings and residue quality indices. Unlike the incubation study, phase-specific decay rates were not calculated.

2.7. Statistical Methods

The effect of variety on decomposition responses was assessed using one-way ANOVA with individual jars as the unit of replication in the incubation study (n = 8 per variety). Responses included cumulative C mineralized, percent C remaining, full-trajectory decay rate, Phase 1 decay rate, and Phase 2 decay rate, with jar-level slope estimates serving as the unit of replication for all decay rate ANOVAs as described above.

In the litterbag study, responses included final mass remaining, decay rate, and intercept. ANOVA of final mass remaining used individual bags retrieved at the final sampling date as the unit of replication (n = 6 per variety). The significance of the variety × time interaction term from the multiple linear regression described above was used to test whether decay rates differed among varieties. Variety-level intercepts were not formally tested for variety-level differences but were included as a response variable in subsequent simple linear regressions against solidness ratings and residue quality indices alongside decay rate and final mass remaining. Unlike the incubation study, phase-specific decay rates were not calculated for the litterbag study. Post-hoc pairwise comparisons were conducted using Tukey's HSD.

The effects of residue quality metrics (laboratory and commercial solidness ratings, aNDF, ADF, hemicellulose, lignin, cellulose, total N, lignin:N ratio, LCI, and C:N ratio) on these same decomposition responses were assessed using simple linear regression of variety-level means in both studies (n = 8 incubation, n = 7 litterbag).

To compare residue cover and SAI across a broader geographic and temporal scope, percent cover and SAI from three site-years (Akron 2025, Akron 2026, and Yuma 2026) were

analyzed using one-way ANOVA with solidness class (Low, Medium, High) as the fixed effect and site-year as a blocking factor. Estimated marginal means were computed and pairwise comparisons conducted using Tukey's HSD, with plot as the unit of replication (n = 3 per solidness class per site-year).

WSS infestation was compared among solidness classes using a chi-square test of independence on the counts of infested and uninfested stems, with individual stems as the unit of observation. Where the overall test was significant, pairwise comparisons between solidness classes were conducted using chi-square tests with a Bonferroni correction for multiple comparisons.

For all models, normality and homoscedasticity were assessed by inspecting Q-Q plots and fitted versus residual plots prior to inference. Significance was assessed at $\alpha = 0.05$. All statistical analyses were conducted in R (version 4.5.2) using tidyverse (dplyr v1.1.4, tidyr v1.3.1, ggplot2 v4.0.0), readxl (v1.4.5), emmeans (v2.0.0), multcomp (v1.4.29), broom (v1.0.10), kableExtra (v1.4.0), RColorBrewer (v1.1.3), and cowplot (v1.2.0).

3. RESULTS

3.1. Incubation Study

Wheat variety significantly predicted cumulative C mineralized, percent C remaining, and full-trajectory and Phase 1 decay rates (all $p < 0.001$), as well as Phase 2 decay rate ($p = 0.004$; Table 2). AP Solid and WB4733 had the fastest Phase 1 decay rates and the lowest percent C remaining at the end of the 134-day incubation (74.4% on average), while Fortify SF had the slowest Phase 1 decay rate and the highest percent C remaining (78.1%; Fig. 2). Phase 2 decay rates also differed significantly among varieties but spanned a much narrower range than

Phase 1 and did not follow the Phase 1 ranking. Full-trajectory decay rates closely tracked the Phase 1 ranking, indicating that early-phase dynamics dominated cumulative C loss over the 134-day incubation.

Neither laboratory solidness nor commercial solidness rating was a significant predictor of cumulative C respired, percent C remaining, or Phase 1, Phase 2, or full-trajectory decay rate (Table 3, Fig. 3a & b). Coefficients for both solidness ratings were negative for percent C remaining, suggesting a weak, non-significant trend toward greater decomposition with increasing solidness.

Several residue quality indices were significant predictors of decomposition outcomes. Higher fiber content, indicated by aNDF, ADF, and hemicellulose, was associated with lower cumulative C respired, greater percent C remaining, and slower Phase 1 decay (Table 3, Fig. 3). Higher total N and lower C:N ratio were associated with greater cumulative C respired, lower percent C remaining, and faster Phase 1 decay (Fig. 3). In Phase 2, only hemicellulose and aNDF were significant predictors, both associated with slower decay. Although the absolute spread in Phase 2 rates among varieties was small, variety remained a significant source of variation (Table 2). Cellulose, lignin, and lignin:N ratio were not significant predictors of any incubation response (Table 3).

3.2. Litterbag Study

Findings from residue decay in litterbags showed that final mass remaining differed significantly among wheat varieties in the 229-day experiment (Table 4; Fig. 4). AP Solid and WB4733 showed the greatest mass loss with only 75% remaining, while Byrd CL Plus and Fortify SF retained approximately 7% more mass on day 229 (Fig. 4). The non-significant variety × time interaction indicated that varieties did not differ in decay rate (Table 4). Variety-

level intercepts indicated that varieties diverged primarily in the magnitude of early mass loss rather than in subsequent decomposition rate, with Fortify SF showing the smallest initial loss and AP Solid the largest (Table 4; Fig. 5).

Several residue quality indices were significant predictors of final mass remaining and intercept. Higher aNDF, ADF, and hemicellulose were positively associated with mass remaining and with the Y-intercept, while higher total N and lower C:N ratio were negatively associated with final mass remaining (Table 5). No residue quality index significantly predicted decay rate. Cellulose, lignin, and lignin:N ratio were not significant predictors of any litterbag response. Neither laboratory-measured nor commercial solidness rating significantly predicted final mass remaining, intercept, or decay rate (Table 5).

3.3. Residue Cover and WSS Infestation Monitoring

When residue cover was compared across solidness classes using data from three site-years, high solidness varieties maintained significantly greater residue cover than medium solidness varieties, while low solidness did not differ significantly from either (Fig. 6). Solidness class had no significant effect on SAI (Table 6). WSS infestation rate differed significantly among solidness classes (Fig. 7), with the high solidness class having a significantly lower infestation rate than the medium, while the low solidness class had intermediate values. Aboveground biomass collected on the final date in Akron in 2026, did not differ significantly among solidness classes.

4. DISCUSSION

4.1. Solidness and Residue Quality as Drivers of Decomposition

We hypothesized that stem solidness would influence structural chemistry in ways that slow microbial activity and overall residue decomposition rate. Neither the lab-measured solidness rating, nor commercial solidness significantly predicted any decomposition metric in either the litterbag or incubation study. Additionally, solidness was not clearly related to any of the other litter quality parameters measured (e.g., total N, lignin). This suggests that contrary to our hypothesis, the solidness trait is not associated with residue chemical complexity in ways that strongly affect microbial decomposition processes. Solidness ratings describe the degree of pith fill in the stem (Sherman et al., 2010; DePauw & Read, 1982) but say nothing about the labile C fractions, fiber content, or N availability that have been shown to regulate decomposer activity in other studies (e.g., Trinsoutrot et al., 2000; Henriksen & Breland, 1999).

Beyond this lack of a mechanistic link, a methodological feature of our data further complicates any relationship between solidness and decomposition. For several varieties, the lab-measured ratings diverged from the published commercial ratings, likely reflecting the environmentally variable nature of pith expression. Our ratings were measured on plants grown at a single location (Fort Collins, Colorado) and therefore reflect expression under one set of environmental conditions, whereas commercial ratings are typically derived from evaluations across multiple environments and seasons. Reduced light during stem elongation suppresses pith development and the associated WSS resistance (Holmes, 1984), and higher sowing density reduces pith expression (Beres et al., 2012; Nilsen et al., 2016). Nutrient availability may also play a role, though growing environment appears to be the stronger influence, as fertility

treatments have had little effect on pith expression relative to location and weather (DePauw & Read, 1982; Beres et al., 2012). Under the growing conditions at our site, several varieties expressed measured ratings well below their commercial designations; AP Solid, for example, carries a commercial rating of 16 yet expressed a measured rating of just 7, with similar but less extreme differences observed for WB4444 and Amplify SF. Because varieties rated as solid under one set of conditions may express semi-solid or even hollow stems elsewhere (Pluta et al., 2021), our single-site measurements likely captured only one realization of each variety's potential solidness, further weakening any relationship between the solid stem traits expression and decomposition. It is also worth noting that solid-stem varieties accumulate greater pith volume, which serves as storage capacity for water-soluble carbohydrates that are mobilized during grain fill (Saint Pierre et al., 2010; Scofield et al., 2009); if residual labile C concentrations are higher in solid-stem varieties at harvest, this could counteract any inhibitory effect on decay associated with greater physical density, offering an additional explanation for why greater solidness did not translate into slower decomposition as hypothesized.

While solidness was not related to decomposition, the other residue quality metrics were strong predictors of decomposition across both studies. Fiber content, including measures of aNDF, ADF, and hemicellulose, were among the most significant predictors of both cumulative C mineralized and final mass remaining, consistent with the well-established role of structural C in slowing microbial decomposition (Johnson et al., 2007). High fiber content reduces the accessibility of C to decomposers both by increasing the proportion of recalcitrant material relative to labile substrates and by increasing substrate complexity, as the structural fibers measured by aNDF and ADF form a lignocellulosic matrix whose physical and chemical associations resist microbial colonization and enzymatic breakdown (Berg & McClaugherty,

2014). Total N and C:N ratio were also strong predictors of decomposition, consistent with the established role of N availability as a key constraint on decomposer activity (Taylor et al., 1989). Microbial decomposers require N to synthesize cellular biomass and extracellular enzymes, meaning that residues with low N concentration relative to C present a stoichiometric limitation on microbial growth and activity (Averill & Waring, 2018; Recous et al., 1995). When residue C:N ratios exceed microbial demand, decomposers must scavenge inorganic N from the surrounding soil, drawing down soil N availability and slowing decomposition (Henriksen & Breland, 1999). As labile C fractions are preferentially consumed, the remaining substrate becomes increasingly dominated by recalcitrant fiber (Gao et al., 2016), and the persistence of these structural fractions becomes a primary control on late-stage decay (Berg & McClaugherty, 2014), consistent with the significant relationships between fiber fractions (hemicellulose and aNDF) and slower Phase 2 decay observed here.

Lignin:N ratio and LCI were comparatively poor predictors in both studies, which may be a consequence of the relatively early decomposition stage captured here. With approximately 23–27% mass loss in the incubation study and 18–25% in the litterbag study, we suspect that the system had not yet reached the stage where lignin becomes the dominant control on decomposition rate. Lignin-based indices tend to gain predictive power later in the decomposition process, when labile fractions have been exhausted (Melillo et al., 1989). This pattern has been observed in cereal residue studies where labile fractions are lost first and the proportion of lignin increases as decomposition progresses (Gao et al., 2016). The transition to lignin-dominated decomposition is thought to occur at approximately 40% cumulative mass loss, when labile carbohydrate fractions are sufficiently depleted that recalcitrant aromatic structures become the primary substrate for decomposers (Berg & McClaugherty, 2014). The substantial

variation in lignin content observed across varieties in this study, ranging from 13.5% in Amplify SF to 43% in Windom SF, may therefore have had limited influence on decomposition rates during the study period but could become a more important driver of differences in residue persistence over a second year of decay.

4.2. Incubation versus Litterbag Decomposition

Decomposition proceeded noticeably faster in the laboratory incubation than in the field litterbag study. The incubation resulted in approximately 23–27% mass loss over 134 days, while the field litterbag study captured roughly 18–25% mass loss over 229 days. This finding is expected given that moisture and temperature conditions were maintained at near optimal conditions for microbial growth throughout the incubation experiment. The difference in decomposition rate is consistent with studies showing that field decomposition in semiarid and dryland systems is strongly limited by moisture availability (Douglas et al., 1980), and that laboratory incubations under optimal conditions can substantially overestimate field decomposition rates (Rinkes et al., 2013). It should also be noted that the two approaches measure somewhat different aspects of decomposition. The incubation quantifies C mineralization through microbial respiration alone, while the litterbag captures mass loss through a combination of microbial respiration, dissolved organic C leaching, and physical fragmentation. Photooxidation is also an important decomposition pathway for surface residues in dryland systems, where high solar radiation and sparse canopy cover increase direct litter exposure (Adair et al., 2017), though its contribution in this study was likely limited given that litterbags were placed within the existing litter layer, reducing direct sunlight exposure. Direct comparisons between the two approaches should be interpreted with these differences in mind (Rubino et al., 2007; Cotrufo et al., 2010). Despite this difference in rate, the relative ranking of

varieties was consistent across both studies, suggesting that the importance of residue chemical properties is consistent across environmental conditions.

One notable feature of the litterbag data was a rapid initial mass loss at the first retrieval date, likely attributable to leaching of soluble compounds rather than true microbial decomposition (Collins et al., 1990). Water-soluble carbohydrates, soluble N, and other labile compounds can be rapidly lost through leaching in the first rainfall events following deployment (Gao et al., 2016; Marschner et al., 2011), inflating apparent early decomposition rates. In this study, a substantial rainfall event of 67 mm occurred on September 23, four days before the first litterbag collection, with no significant precipitation recorded between bag placement on August 25 and that event, suggesting that much of the early leaching loss was concentrated in this single event. Variety-level Y-intercepts, which capture this early mass loss signal, were significantly predicted by hemicellulose, aNDF, ADF, and total N, suggesting that residue chemical quality plays an important role in determining initial leaching losses. While the lack of a significant relationship across both the controlled incubation and field litterbag study suggests that solidness is not a good predictor of decay, we note that both studies exclude larger decomposer organisms (e.g., earthworms, isopods, beetles; Cotrufo et al., 2010). Soil macroinvertebrates are important in the litter fragmentation process and in mixing residues with soil, consequently facilitating microbial growth and access to decomposing residues, greatly accelerating decomposition rates (Zimmer et al., 2005). Thus, these organisms warrant greater consideration in future research since they are likely to be more directly impacted by stem pith, a trait largely developed as a physical deterrent to another invertebrate, WSS (Peirce et al., 2022).

4.3. Residue Cover and Silhouette Area Index

Across three site-years, high solidness plots maintained significantly greater residue cover than medium solidness plots, while low solidness was intermediate (Fig. 6), suggesting that solidness class differences in residue cover persistence may be real but modest in magnitude. No significant solidness class effect was detected for SAI across the three site-years (Table 6), which is perhaps unsurprising given that SAI and residue cover are likely driven more by stem orientation and the physical structure of standing stubble than by decomposition rate alone (Simão et al., 2021; Steiner et al., 2000). Initial biomass production and stem density, including potential variety-level differences in tillering, may also play an important role in determining SAI independently of decomposition dynamics, though this warrants further investigation. Residue cover was high across all solidness classes and site-years, suggesting that functional implications for soil cover may be limited under the conditions observed here. Broader geographic representation and multi-year assessments of residue cover persistence are needed to more fully understand the implications of solidness class for soil health and related agroecosystem functions.

WSS infestation rate, measured at Akron in February and April 2026, differed significantly among solidness classes, with WB4733 exhibiting the lowest infestation rate and Fortify SF the highest (Fig. 7). This pattern is partially consistent with the expectation that greater stem solidness confers resistance to WSS oviposition and larval survival, and with the directional differences in residue cover observed across site-years, as WSS-driven lodging is known to reduce standing stubble height and increase vulnerability to wind erosion (Beres et al., 2025). However, the intermediate solidness variety Fortify SF had a higher infestation rate than

Canvas, the hollow variety, which does not follow a simple solidness gradient and suggests that other factors may be influencing WSS oviposition behavior independently of solidness.

WSS infestation is known to be influenced by a range of cultivar traits beyond solidness alone (Bathini et al., 2023), and oviposition is influenced by stem height and proximity to the emergence site, with infestation rates typically highest at field edges nearest the previous year's stubble and declining toward field centers (Nansen et al., 2005), and females showing no discrimination between infested and un-infested hosts (Buteler et al., 2009). Hollow-stem cultivars also vary considerably in their effects on larval survivorship and adult fitness independently of pith expression (Cárcamo et al., 2005), pointing to cultivar traits beyond stem structure, including plant chemistry, as potential drivers of the patterns observed here.

This chemical variation can shape how ovipositing females select hosts. Females rely on volatile cues to discriminate among host plants, and cultivars differ in the production of behaviorally active volatiles that influence oviposition preference (Piesik et al., 2008; Weaver et al., 2009; Buteler & Weaver, 2012). Because these volatile differences can occur independently of pith expression, it is possible that the cultivars evaluated here differed in chemical traits that influenced WSS oviposition apart from solidness, which may contribute to the departures from a simple solidness gradient observed in the infestation data.

These results should be interpreted cautiously given that this was an observational field count rather than a controlled infestation trial and replication at the plot level was limited. Beyond these direct resistance effects, WSS may also influence residue dynamics more broadly as an early-arriving macroinvertebrate. Larval feeding and stem girdling fragment internal stem tissue and bring residues into closer contact with the soil surface, potentially facilitating microbial colonization and accelerating decomposition in ways not captured by our controlled

studies. Whether variety-level differences in WSS infestation rates translate into meaningful differences in post-harvest residue decomposition and cover persistence represents another important area for future research.

4.4. Management Implications and Future Directions

This study was motivated in part by the practical question of whether solid-stem wheat varieties, already valued for WSS resistance, might also provide greater residue persistence and soil cover benefits relative to hollow-stem varieties. For residue decomposition, our findings do not support this idea. Neither laboratory-measured nor commercial solidness rating significantly predicted any decomposition response in either the incubation or litterbag study. A significant solidness class effect was detected in residue cover compared across three site-years, with medium solidness plots maintaining less cover than high solidness plots and low solidness intermediate between the two. This pattern does not follow a simple solidness gradient and should be interpreted cautiously given the modest effect size and limited number of varieties per solidness class, suggesting that growers selecting solid-stem varieties for WSS management need not expect large or consistent residue cover advantages from that selection alone.

The more actionable finding for residue management is that fiber fractions and N availability were far stronger predictors of decomposition than solidness across both studies, consistent with the well-established role of residue chemical quality, particularly fiber content and N concentration, in governing decomposition rate (Johnson et al., 2007; Talbot & Treseder, 2012). Among fiber fractions, aNDF and ADF emerged as consistent predictors across both the incubation and litterbag studies, consistent with prior work identifying ADF and aNDF as strong predictors of decay in dryland cereal residues (Stubbs et al., 2009). This is practically useful because aNDF and ADF are standard measurements in routine forage and crop quality testing

(Undersander et al., 1993), making them readily accessible to growers and agronomists without requiring specialized decomposition trials or laboratory infrastructure. When considered alongside total N, which was also a strong predictor across both studies, these three measurements together provide a clearer and more complete picture of residue decomposition potential, capturing both the structural fiber pool that inhibits microbial decomposition and the nitrogen availability that regulates decomposer activity.

Critically, these chemical properties are sensitive to management as well as variety. Nitrogen fertilization rate and timing influence residue N concentration (Blumenthal et al., 2008; Trinsoutrot et al., 2000), and fiber fractions may also vary with N rate, though responses are inconsistent: Zheng et al. (2021) found hemicellulose increased at moderate N rates, while Murozuka et al. (2014) found cellulose unaffected, but lignin peaked at intermediate rates. Water availability during grain fill may further influence how much water-soluble carbohydrate is mobilized from stem tissue into the grain, with photosynthesis-limiting conditions potentially reducing residue carbohydrate concentration at harvest (Saint Pierre et al., 2010). Nitrogen management carries an important tradeoff, however: because nitrogen drives both grain and biomass production, reducing it to slow decomposition would also reduce grain and biomass yields. Growers may therefore have some, though constrained, capacity to influence residue persistence through management independently of variety and understanding how N fertilization and water availability interact with variety selection to shape residue chemical quality, decomposition, and cover persistence in dryland systems represents a practically relevant and largely unexplored direction for future research.

Several important questions remain and limit the strength of recommendations that can be drawn from this study. The residue cover monitoring component was limited to one variety per

solidness class across three site-years with three replicate plots per variety, which constrains the ability to detect variety-level differences in cover persistence. A more systematic evaluation incorporating full-season residue cover monitoring across multiple site-years, with a broader range of varieties, various management treatments, greater replication per solidness class, and decomposition assessments that include the soil macroinvertebrate community and WSS itself, would provide a stronger basis for understanding how solidness influences residue dynamics over time and across variable environmental conditions.

5. CONCLUSION

This study set out to evaluate whether the solid stem trait in winter wheat influences residue decomposition rates and persistence, motivated by the possibility that solid stem varieties could provide dual benefits in dryland systems by managing WSS pressure while also extending protective soil cover. Neither laboratory-measured nor commercial solidness rating significantly predicted any decomposition response in either incubation or litterbag study, indicating that the solidness trait does not translate into meaningful differences in residue chemical quality or decomposition rate under the conditions studied here. Results were more nuanced for residue cover, as residue cover compared across three site-years indicated that plots with high solidness varieties maintained greater cover than medium solidness plots. This trend was directionally consistent across site-years but modest in magnitude, and growers selecting solid stem varieties for WSS resistance should not expect large or reliable residue cover advantages from that selection alone, at least in the time frame considered here.

Residue chemical quality was a far stronger predictor of decomposition than solidness. Fiber fractions, particularly aNDF, ADF, and hemicellulose, and N availability indicated by total

N and C:N ratio, explained most of the variation in decomposition responses across varieties in both studies, with variety rankings remaining consistent across the controlled incubation and field litterbag environments despite large differences in overall decomposition rate between the two settings. These findings suggest that residue chemical quality, rather than stem morphology, is the more reliable basis for anticipating decomposition outcomes in dryland wheat systems, and that understanding how fertilization and water management interact with variety selection to shape residue chemical composition represents a promising and largely unexplored pathway toward improved soil health outcomes in dryland wheat agroecosystems.

TABLES AND FIGURES

Table 1. Residue quality characteristics and stem solidness ratings for eight winter wheat varieties used in decomposition studies.

Variety	Lab Measured Solidness[a]	Commercial Solidness Rating[a]	Total N (%) [b]	ADF (%) [b]	aNDF (%) [b]	Hemicellulose (%) [b]	Cellulose (%) [b]	Lignin (%) [b]	Lignin:N Ratio [b]	LCI [b]	C:N Ratio [b]	Study[c]
Byrd CL Plus	5	5	0.49	50.1	76.7	26.6	37.4	12.7	25.83	0.2	92	I, L
Canvas	5	5	0.61	46.8	71.9	25.0	10.4	36.4	59.75	0.5	73	I, L, RC
AP Solid	7	16	0.74	40.9	64.0	23.1	21.2	19.8	26.68	0.3	62	I, L
WB4444	9	14	0.56	45.7	75.0	29.2	29.3	16.4	29.36	0.2	81	I, L
Fortify SF	10	12	0.40	50.0	77.5	27.5	29.3	20.8	51.83	0.3	110	I, L, RC
Amplify SF	12	17	0.48	47.5	73.2	25.7	34.0	13.5	28.41	0.2	94	I, L
Windom SF	12	15	0.57	47.8	72.8	25.0	4.7	43.2	75.5	0.6	78	I, L
WB4733	19	19	0.57	44.0	65.9	21.9	28.5	15.5	27.24	0.2	78	I, L, RC

[a] Laboratory measured solidness rating and commercial solidness rating are shown on a scale of 5–25.

[b] Fiber fractions (ADF, aNDF, hemicellulose, cellulose, lignin) are expressed as percent of dry matter. Total N is percent of dry matter. Lignin:N ratio and C:N ratio are dimensionless. LCI is the lignocellulose index.

[c] Refers to study in which each variety was used: incubation (I), litterbag (L), and residue cover (RC) studies.

Table 2. Mean decomposition responses for eight winter wheat varieties during a 134-day incubation study. Phase 1 (day 0–10), Phase 2 (day 10–134), and full trajectory decay rates, and C remaining by variety, arranged by solidness rating. Values are means ± SE. p values from one-way ANOVA with variety as predictor are shown in the bottom two rows (variety df = 7 and residual df = 56 for all responses).

Variety	Solidness Rating	Phase 1 Decay Rate (yr^{-1}) ± SE	Phase 2 Decay Rate (yr^{-1}) ± SE	Full Trajectory Decay Rate (yr^{-1}) ± SE	C Remaining (%) ± SE
Byrd CL Plus	5	-2.745 (0.085)	-0.479 (0.009)	-0.593 (0.011)	77.7 (0.31)
Canvas	5	-3.158 (0.054)	-0.514 (0.018)	-0.647 (0.021)	75.8 (0.63)
AP Solid	7	-3.483 (0.027)	-0.528 (0.009)	-0.688 (0.010)	74.5 (0.30)
WB4444	9	-2.964 (0.057)	-0.496 (0.013)	-0.623 (0.015)	76.7 (0.37)
Fortify SF	10	-2.419 (0.027)	-0.492 (0.007)	-0.603 (0.007)	78.1 (0.24)
Amplify SF	12	-2.831 (0.026)	-0.496 (0.019)	-0.622 (0.020)	77.0 (0.53)
Windom SF	12	-3.041 (0.050)	-0.550 (0.014)	-0.679 (0.016)	75.2 (0.49)
WB4733	19	-3.510 (0.022)	-0.550 (0.020)	-0.703 (0.016)	74.3 (0.41)
p- value					
Variety		< 0.001	< 0.01	< 0.001	< 0.001

Table 3. Pearson correlation coefficients for associations between residue quality indices and decomposition responses across eight winter wheat varieties in a 134-day incubation study. Results presented are for Phase 1 (day 0–10), Phase 2 (day 10–134), and full trajectory decay rates (days 0-134), and C remaining. Significance indicated as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Predictor	Phase 1 Decay Rate (yr^{-1})	Phase 2 Decay Rate (yr^{-1})	Full Trajectory Decay Rate (yr^{-1})	C Remaining (%)
Total N	-0.866**	-0.558	-0.725*	-0.822*
Cellulose	0.354	0.658	0.552	0.539
Hemicellulose	0.782*	0.753*	0.829*	0.812*
ADF	0.881**	0.561	0.768*	0.825*
aNDF	0.935***	0.720*	0.888**	0.915**
Lignin	-0.119	-0.516	-0.351	-0.323
Lignin:N ratio	0.189	-0.348	-0.124	-0.050
C:N Ratio	0.900**	0.621	0.757*	0.858**
LCI	-0.224	-0.586	-0.444	-0.421
Lab solidness	-0.288	-0.583	-0.511	-0.398
Commercial solidness	-0.386	-0.539	-0.570	-0.490

Table 4. Initial mass loss and decay rates for seven winter wheat varieties during a 229-day litterbag experiment, arranged by solidness rating. Initial mass loss (y-intercept) and decay rate were estimated from a multiple linear regression of log-transformed mass ratio against time, variety, and their interaction. Values are means ± SE. p values from the multiple linear regression are shown in the bottom rows (variety df = 6, residual df = 196)

Variety	Solidness Rating	Initial Mass Loss (y-intercept)	Decay Rate (yr^{-1}) ± SE
Byrd CL Plus	5	-0.167 (0.008)	-0.069 (0.021)
Canvas	5	-0.188 (0.007)	-0.100 (0.020)
AP Solid	7	-0.258 (0.011)	-0.083 (0.021)
Fortify SF	10	-0.145 (0.007)	-0.104 (0.021)
Amplify SF	12	-0.196 (0.007)	-0.091 (0.021)
Windom SF	12	-0.213 (0.009)	-0.075 (0.021)
WB4733	19	-0.242 (0.007)	-0.085 (0.021)
p-values			
Time			<0.001
Variety			<0.001
Variety x Time			0.888

Table 5. Pearson correlation coefficients between residue quality indices and stem solidness ratings and decomposition responses across seven winter wheat varieties in a 229-day litterbag decomposition study conducted between Aug 2025 and April 2026, near Akron, CO. Significance: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Predictor	Initial Mass Loss (y-intercept)	Decay Rate (yr^{-1})	Final Mass Remaining (%)
Total N	-0.838*	0.207	-0.785*
Cellulose	0.291	0.077	0.296
Hemicellulose	0.934**	-0.184	0.922**
ADF	0.929**	-0.018	0.936**
aNDF	0.959***	-0.085	0.959***
Lignin	-0.040	-0.084	-0.044
Lignin:N Ratio	0.253	-0.208	0.232
C:N Ratio	0.850*	-0.276	0.800*
LCI	-0.147	-0.070	-0.150
Lab solidness	-0.373	0.003	-0.411
Commercial solidness	-0.625	0.004	-0.649

Table 6. Final date Silhouette area index (SAI) by stem solidness class across three site-years (Akron 2025, Akron 2026, and Yuma 2026) and final date aboveground biomass by solidness class from Akron 2026. SAI values are estimated marginal means ± SE from a one-way ANOVA with site-year as a blocking factor (n = 3 per solidness class per site-year). Biomass values are means ± SE (n = 3 per solidness class). p values from one-way ANOVA with solidness class as predictor.

Solidness Class	SAI (m^2 m^{-2})	Biomass (g)
Low	0.497 (0.024)	205.96 (37.00)
Medium	0.433 (0.026)	176.60 (40.86)
High	0.474 (0.026)	216.92 (47.70)
p-values		
Solidness Class	0.406	0.790

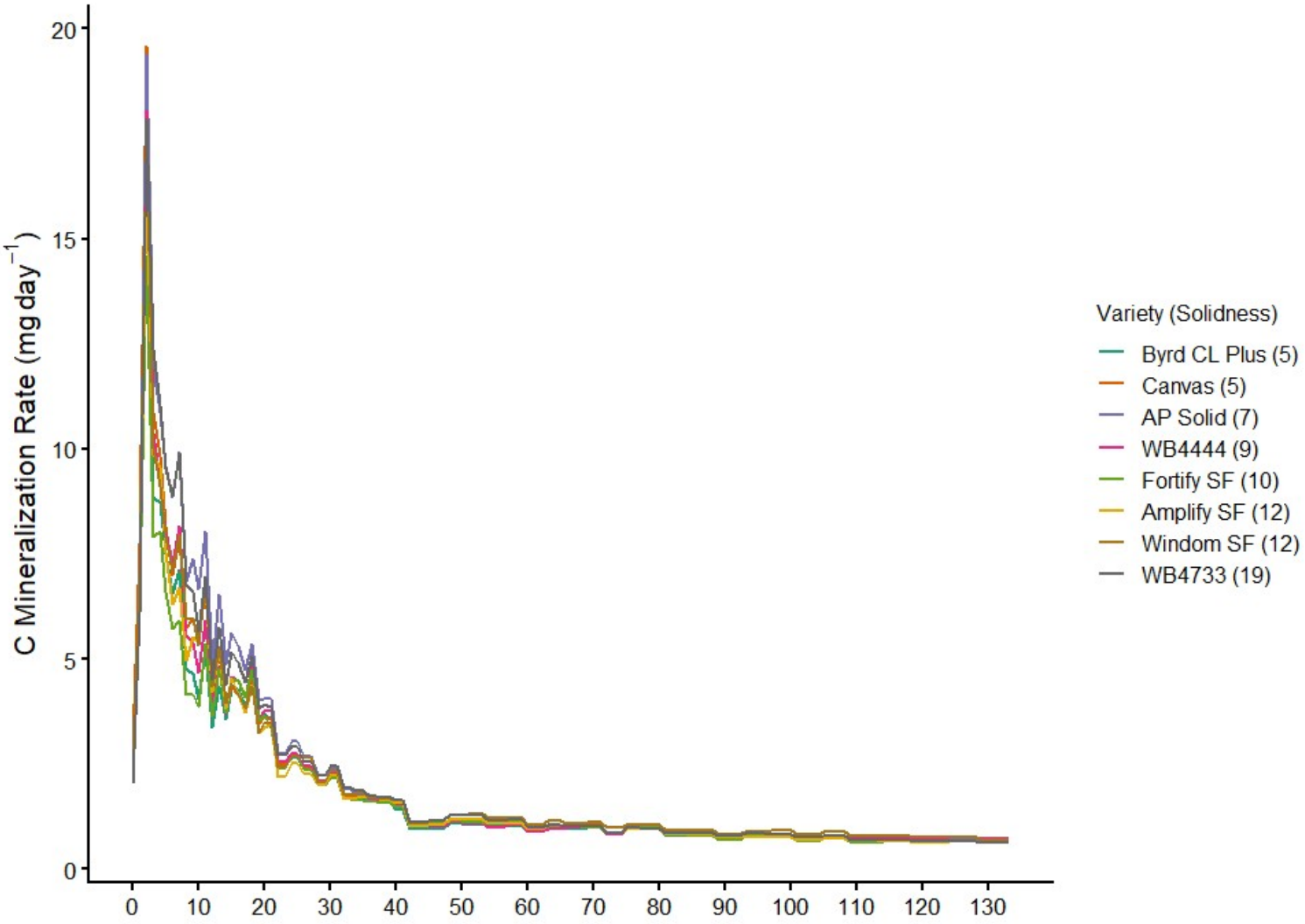

Figure 1. Daily C mineralization (mg) for eight winter wheat varieties over a 134-day laboratory incubation. Points represent individual jar observations (n = 8 per variety) and lines represent variety means. Varieties are ordered by increasing solidness rating as shown in the legend. The rapid decline in mineralization rate during the first 10 days reflects preferential consumption of labile C fractions, followed by a transition to slower decomposition of more recalcitrant material.

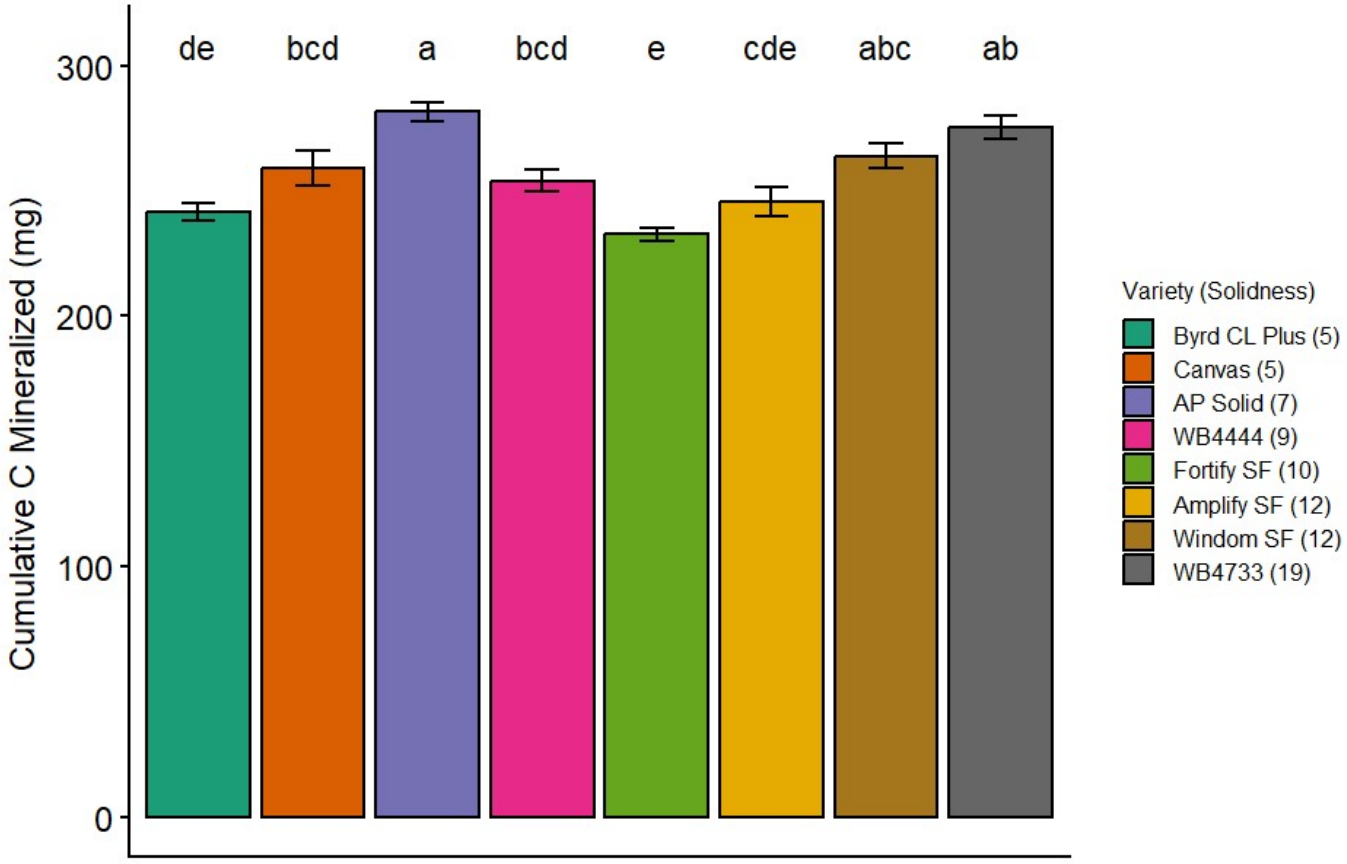

Figure 2. Mean cumulative C mineralized for eight winter wheat varieties during a 134-day incubation experiment study. Bars represent variety means ± SE (n = 8). Varieties are ordered from hollow to most solid. Different letters above bars indicate significant differences between varieties based on Tukey's HSD post-hoc test ($\alpha = 0.05$).

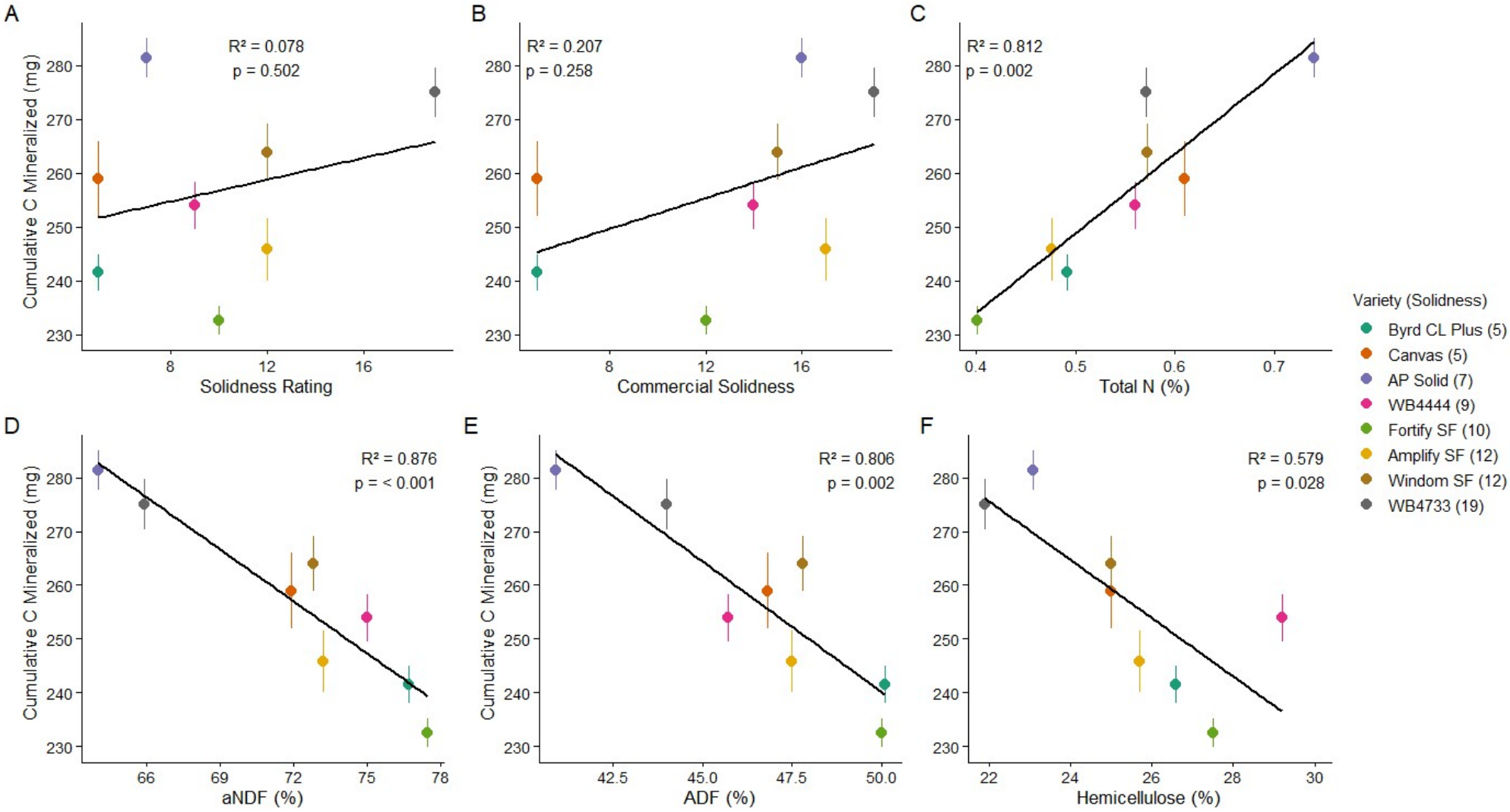

Figure 3. Relationships between residue quality indices and cumulative C mineralized for eight winter wheat varieties during a 134-day incubation. All measured residue quality indices were regressed against cumulative C mineralized, including laboratory-measured solidness rating (A), commercial solidness rating (B), total N (C), aNDF (D), ADF (E), and hemicellulose (F). Lignin, cellulose, lignin:N ratio, and lignocellulose index were not significant predictors and are not shown; C:N ratio was a significant predictor but is not shown. Each point represents a variety mean (n = 8) ± SE. R^2 and p-values are from simple linear regression. Varieties are colored by solidness rating as shown in the legend.

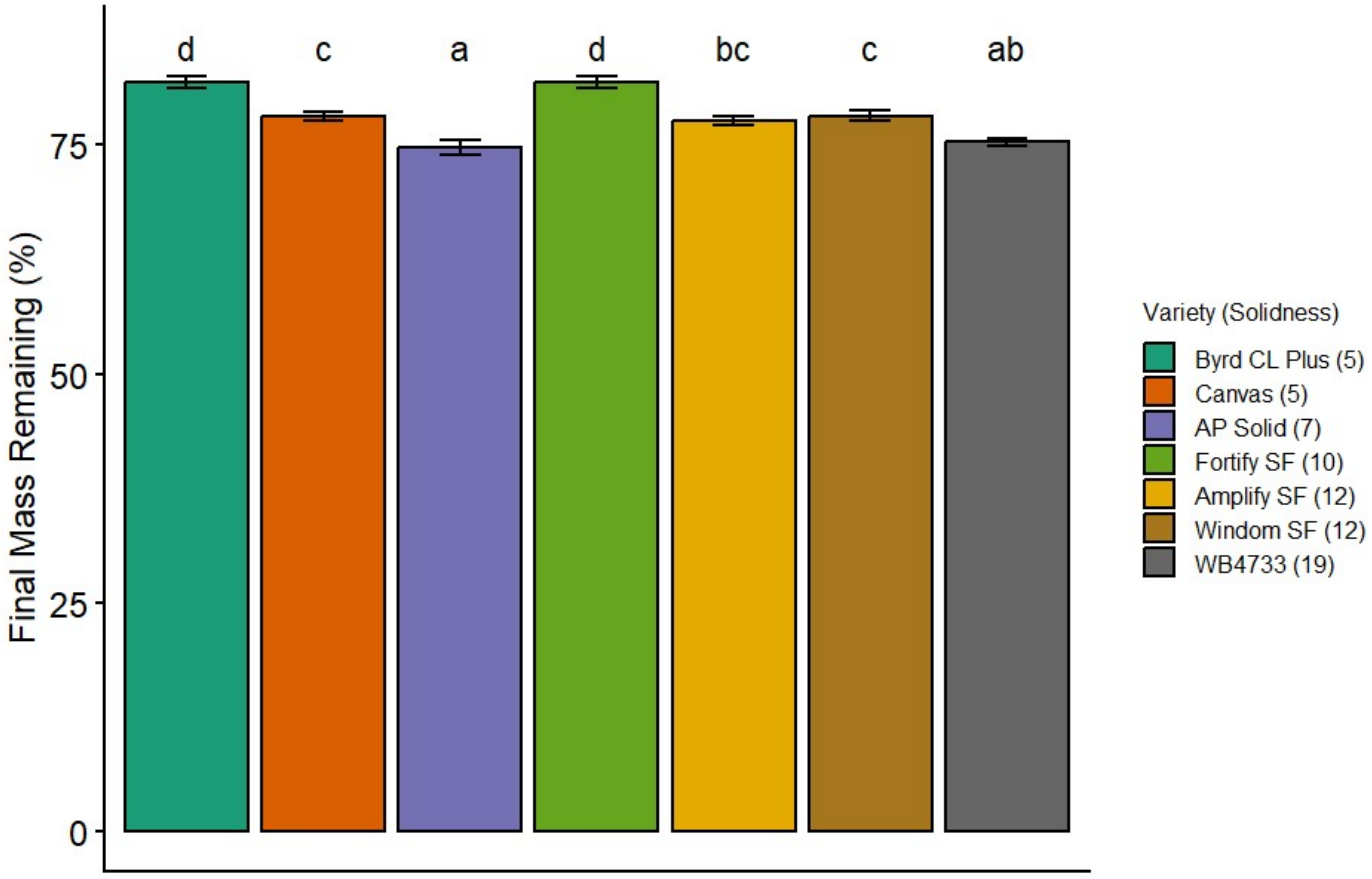

Figure 4. Mean final mass remaining for seven winter wheat varieties after 229 days in a litterbag experiment. Bars represent variety means ± SE (n = 6). Varieties are ordered from hollow to most solid. Different letters above bars indicate significant differences between varieties based on Tukey's HSD post-hoc test ($\alpha = 0.05$).

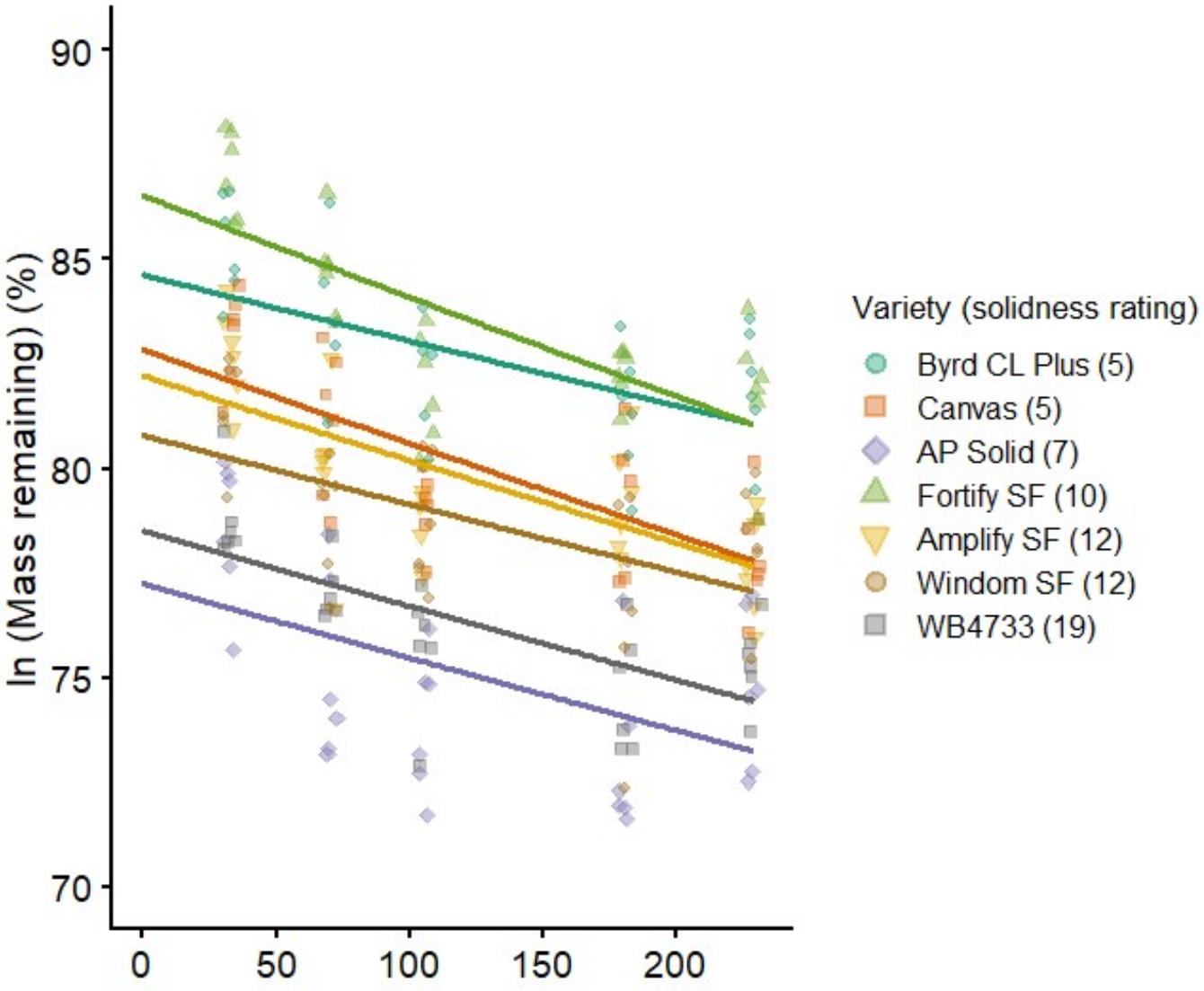

Figure 5. Mass remaining (%) over 229 days for seven winter wheat varieties in a litterbag experiment conducted near Akron, CO. Lines represent variety-level linear regressions fit to natural log-transformed mass ratio; points are individual bag observations (n = 6 per variety per collection date). Varieties are ordered by increasing solidness rating (shown in parentheses).

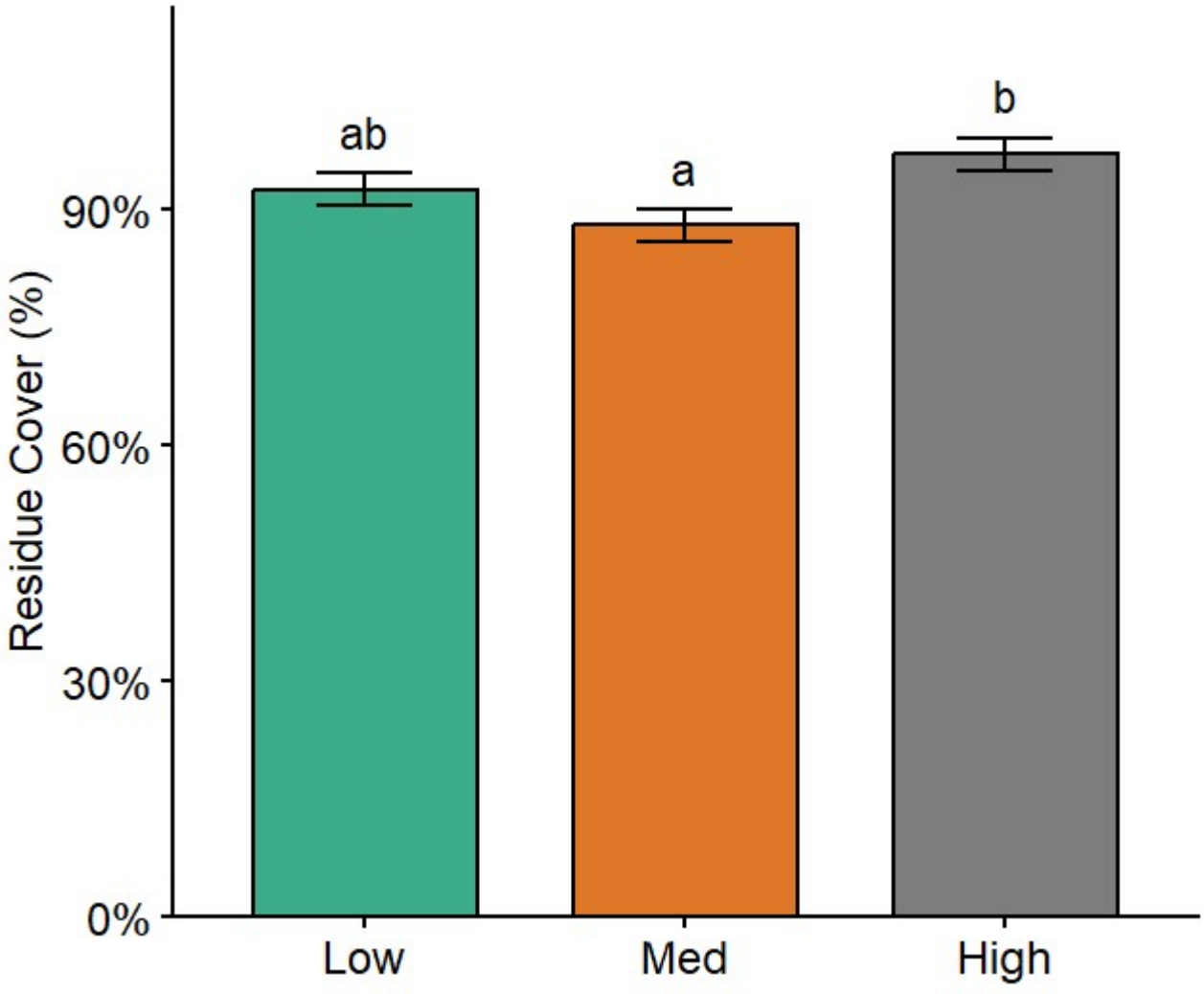

Figure 6. Mean residue cover (%) by stem solidness class (Low, Medium, High) across three site-years (Akron 2025, Akron 2026, and Yuma 2026). Bars represent estimated marginal means ± SE from a one-way ANOVA with site-year as a blocking factor. Different letters above bars indicate significant differences between solidness classes based on Tukey's HSD post-hoc test ($\alpha = 0.05$).

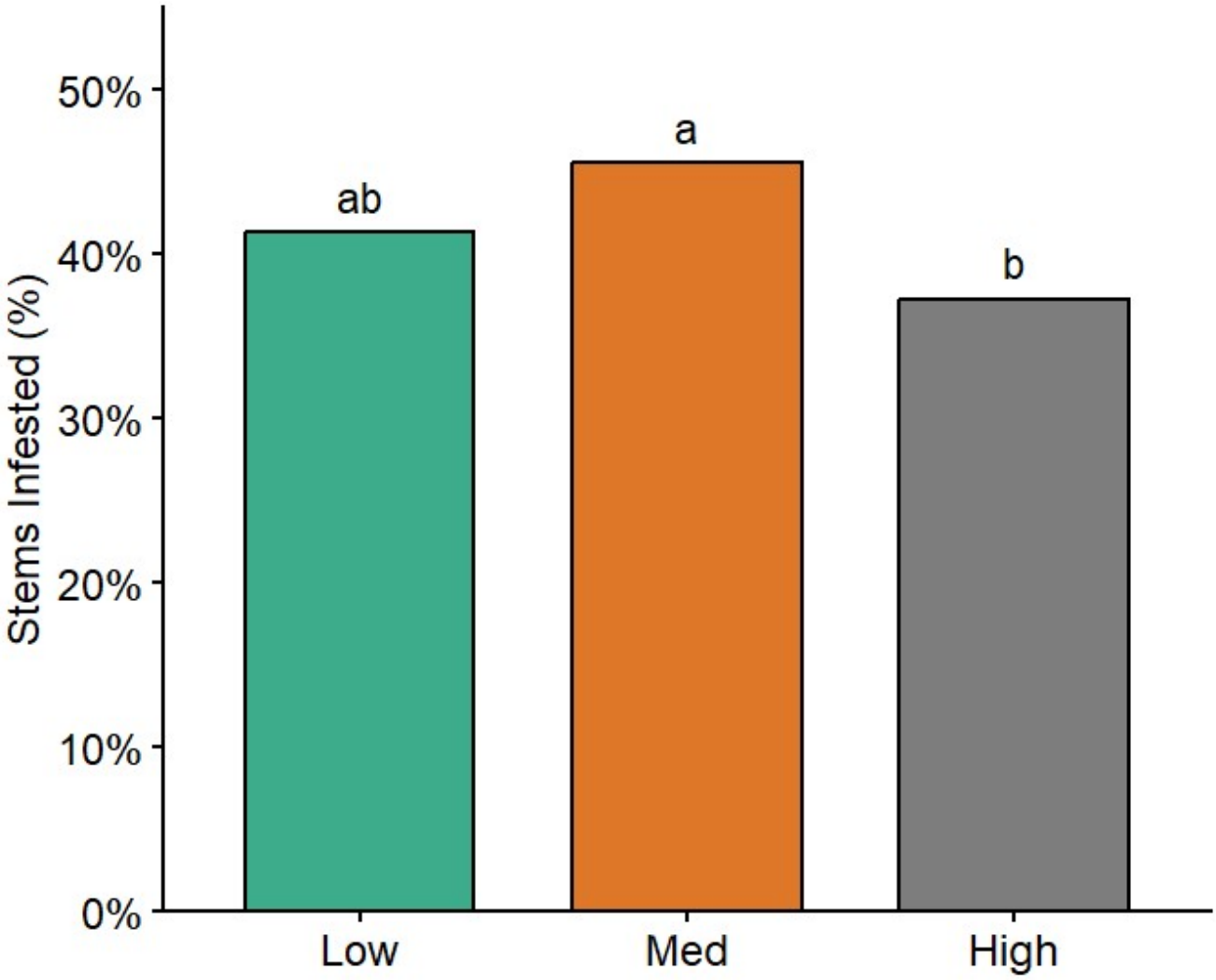

Figure 7. Wheat stem sawfly (WSS) infestation rate across three winter wheat cultivars varying in stem solidness class assessed at the Akron USDA-ARS Central Great Plains Research Station in February and April 2026. Solidness classes correspond to Canvas (Low, solidness = 5), Fortify SF (Med, solidness = 12), and WB4733 (High, solidness = 19). Bars show the percentage of stems infested by WSS. Letters above bars indicate significant differences in WSS infestation rate between solidness classes based on pairwise chi-square tests with Bonferroni correction (overall χ^2 test, $p < 0.05$). Total stems sampled: Low n = 671, Medium n = 646, High n = 623

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