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Evaluating Traits Influencing Hybrid Wheat Seed Production Using a Double Haploid Population Derived from Freeman x Camelot

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EVALUATING TRAITS INFLUENCING HYBRID WHEAT SEED PRODUCTION USING A DOUBLE HAPLOID POPULATION DERIVED FROM FREEMAN X CAMELOT

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Hybrid wheat (*Triticum aestivum* L.) cultivars are preferred for their advanced agronomic traits such as a yield improvement increase up to 20%. However, hybrid cultivars remain difficult to produce on a commercial scale due to inadequate pollen dispersal, the closed nature of the wheat floret and the high cost of inducing sterility or restoring fertility in cleistogamous wheat. Redesigning parent-specific traits and understanding their potential interactions with related agronomic traits are needed to breed improved male lines in hybrid seed production fields. To better understand the genetic control of anther extrusion (AE), 174 double haploid lines derived from Freeman (excellent AE) x Camelot (poor AE) were visually assessed in three different environments in 2020 and 2021. Genotypic differences within the DH population were found in 2021. The best linear unbiased estimators found approximately normal distributions with low (AD, PH), moderate (GYLD), and high (AE, LODG) coefficient of variations. Pearson's correlation coefficient results revealed a significant negative correlation ($r=-0.39^{**}$) between AE and lodging (LOGD). Moderately high broad sense repeatability was calculated (0.66) for AE and other traits in DH population. The contribution of PC_1 and PC_2 to the total variance were 45.6% and 27.3%

respectively and combined explained approximately 70% of the total variance observed in PCA analysis.

Keywords: *Triticum aestivum* L., anther extrusion, hybrid seed production.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. LITERATURE REVIEW

1.1.Hybrid Wheat Seed Production

The best breeding schemes for changing floral traits to create sustainable hybrid seed production requires cross pollination which is difficult in naturally cleistogamous wheat (De Vries, 1971). Hence, the progress in creating wheat hybrids has been less than in naturally outcrossing cereals such as maize (*Zea mays* L.) and rye (*Secale cereale* L.). Hybrid wheat has also fallen behind hybrid rice (*Oryza sativa* L.) which is also naturally self-pollinating. The high rate of self-pollination due to the cleistogamous nature of wheat florets impedes the identification of new heterotic groups by making experimental hybrid production difficult and increases the cost of hybrid seed while potentially reducing the level of hybridity (Easterly et al., 2019a).

The cytoplasmic male sterility (CMS) system was primarily induced to reduce the cost of hybrid seed production and to exploit commercial hybrid vigor by both the private and public sector in the 1960s (Whitford et al., 2013). Following that, the discovery of chemical hybridization agents (CHAs) offered a new opportunity to induce selective male sterility and enhanced the selection of parental lines leading to commercial heterosis (Cisar and Cooper, 2002). Until the turn of the millennium, various hybrid wheat development efforts were carried out using both CMS and CHAs, however, few commercial hybrids were successfully developed. The narrow germplasm resources of restorer of fertility (*Rf)* lines and low genetic diversity among the male sterile lines and restorer lines were primary reasons for the partial success of CMS (Garst, 2020). On the other hand, the self-pollinated nature of wheat, and the expensive inputs and phytotoxic effects on female plants hampered

the potential of the CHA approach (Kempe et al., 2011; Stoll, 2020). Although hybrid wheat studies have been conducted for several decades, breeders and researchers need improved ways to develop superior hybrids.

Hard red winter wheat (HRW) is the most widely grown class of wheat in the USA, accounting for approximately 40 percent of total USA production (Wilson, 1983). Hard red winter wheat is a versatile class of wheat grown primarily for its desirable milling and baking characteristics for bread and related products. It is mainly grown in the Great Plains (Nebraska, Colorado, Kansas, Wyoming, Oklahoma, Texas, Montana, South Dakota, North Dakota) and Pacific Northwest. Hard red winter wheat has been widely used in hybrid development programs by public and private sectors (Fufa et al., 2005). The production and genetic gains in pure-line wheat cultivar are 1 % or less per year (Ray et al., 2013), which is too low to meet the projected demand for wheat.

In hybrid wheat breeding, the identification of heterotic patterns for improved grain yield with better tolerance to biotic and abiotic stress is still problematic. The efforts to create hybrid wheat were extensive in the 1980-1990 and then largely stopped, only to be restarted around 2010. Asur Plant Breeding (formerly Saaten-Union Recherche) is one of the few companies that continued throughout this period, but no public research programs did. Without dedicated efforts, the potential of hybrid wheat and the level of hybrid vigor remains poorly studied. Due to the inability to exploit mid-parent or find commercial heterosis, previous hybrids may have had an inadequate range of adaptation in marginal environmental conditions and higher susceptibility to biotic and abiotic stress parameters (Ray et al., 2013; Schnable and Springer, 2013). In hybrids, using genetically divergent

lines is a pivotal approach to improve combining ability and exploiting hybrid vigor (Longin and Reif, 2014). To be economically viable, the level of yield heterosis needs to be sufficient to pay for the increased cost of hybrid seed and hybrid wheat yields must be higher than competitive commercial pure-line cultivars (Adhikari, Ibrahim, et al., 2020; Easterly et al., 2020).

To successfully produce hybrid wheat seed, you need excellent cross pollination in the hybrid seed production fields. Male and female floral traits must be redesigned to provide sufficient cross-pollination to produce experimental and commercial hybrid wheat seed (Whitford et al., 2013; Sade et al., 2022). Successful cross-pollination requires female wheat floret modifications such as gaping florets, with open glumes and exposed and receptive stigmas (Langer et al., 2014; Stoll, 2019). The gaping floret with receptive stigmas will allow better cross pollination (Muqaddasi et al., 2017; Sade et al., 2022). There are few studies on female characteristics. For the male pollinator lines, the most important traits for hybrid wheat seed production are anther extrusion (for adequate pollen shed), anthesis date (for synchronizing pollen shed and female receptivity), plant height (pollen is expected to flow downwards and we expect heterosis for plant height similar to grain yield) and grain yield (for the cost of production and possibly for heterosis). In addition, excellent stem strength is important because lodging will reduce grain yield. Little known about lodging in wheat hybrids, but it is expected that parental lines that lodge may lead to hybrids that lodge.

In our research, we studied anther extrusion (AE), generally considered to be the most important male trait, and anthesis date (AD) as all hybrid seed production fields will require

the female lines to flower slightly ahead of the male lines so that female lines are gaping when the male lines are flowering. We were also interested in the relationship between AE and grain yield, plant height (male lines should be taller than the female line), and lodging. Though not studied in our research, other factors related to hybrid seed production include the duration of the pollination period, and the duration of ovule receptivity (Langer et al., 2014).

1.2. Wheat Anther Extrusion

Anther extrusion is considered as one of the most important traits for efficient cross-pollination and good AE is necessary in male pollinators for hybrid wheat seed production (De Vries, 1972). The extent that anthers extrude outside the wheat floret during anthesis determine the effectiveness of a cross pollination (De Vries, 1973). Anther extrusion can be easily scored visually in field conditions to make initial selection of the superior AE. Additionally, recent studies have emphasized AE is a quantitative agronomic trait, most likely controlled by polygenic inheritance (Skinnes et al., 2010).

The reproductive stage in wheat, including the male parts of the wheat flower is short-lived, generally just a few days. The anthers turn yellow (fully mature pollen) and often shed their pollen in the wheat floret leading to self-fertilization when pollen shedding starts while the glumes are closed and captured by feathery stigma tissues. Fertilization often occurs before AE is observed (De Vries, 1971).

In some genotypes, the anthers extrude and dehisce outside of the floret, hence some pollen is shed outside the floret. The pollen would be available to pollinate unfertilized female plants with high stigma receptivity mediated by wind and gravitational movement

(Whitford et al., 2013). Once anthers extrude from the floret, pollen viability, the second most important male trait, also determines the success of cross pollination. Pollen viability will be affected by environmental factors such as heat stress, wind, low humidity, and can be quickly lost (Garst, 2020).

Anther extrusion is a highly heritable trait with heritability values ranging from 0.62 to 0.91 (Sade et al., 2022; Garst, 2017; Boeven et al., 2016; Skinnes et al., 2010) and can be scored visually. Visually assessments are relatively easily done, and hundreds of lines can be scored as would be needed to evaluate AE in a breeding program or for genetic studies to estimate the role of the genotype (G), environment (E), and the G x E interaction (Garst, 2020). Hence it is important to study AE in relevant germplasm adapted to the environments where hybrid wheat seed will be produced.

In addition, the development of excellent male pollinator lines may affect or be dependent on other agronomic traits. For example, some researchers found that reduced height alleles had a significant negative effect on AE (Lu et al., 2012; Buerstmayr and Buerstmayr, 2016; He et al., 2016). However, other studies Steiner et al. (2019), found that AE and semi-dwarfing alleles (*Rht-B1b* and *Rht-D1b*) were not correlated, hence plant height did not affect AE. Also, semi-dwarfs have been identified with excellent AE (Baenziger et al., 2014). Higher AE also has been associated with higher Fusarium head blight (FHB, incited by Fusarium spp.) tolerance (Skinnes et al., 2010). Alternatively, Graham and Browne (2009) reported that lines with high AE values had reduced FHB severity because extruded anthers provide less of an infection route for FHB pathogens when compared to anthers that are partially extruded. Thus, it is also important to

understand AE and its interactions with other agronomic traits including anthesis date, plant height, grain yield and lodging.

1.3. Wheat Anthesis Date

Anthesis date is one of the most important phenological stages that determines the selection of male and female lines fas those lines need to be synchronized for cross pollination (Mühleisen et al., 2013). A few studies indicated that high repeatability values have been reported for days to anthesis ranging from 0.82 to 0.99 under different environments (Sade et al., 2022; Garst, 2020). Three signaling pathways; vernalization, photoperiod and earliness per se play major roles to regulate anthesis time (Kamran et al., 2014). The optimization of anthesis date to the environments has been an important goal for many hybrid breeding programs to increase adaptation and to identify compatible combinations of parental genotypes (Garst, 2017).

Anthesis date is measured when 50% of the spikes (syn. ears or heads) in a plot have extruded anthers. Pollen shedding anthers are yellow (or purple) and change to white or pale purple after the pollen shed, hence can be visually scored. The change in anther color is a useful sign to confirm anthesis date. Anthesis begins in the florets of central spikelet, and then proceeds towards the basal and apical parts of the spike (De Vries, 1971). Anthesis date differs among genotypes. In some cultivars, anthesis may occur with the anthers not extruding and be hidden in the floret or rarely while the spike is still inside the flag leaf sheath. More commonly anthesis date follows the heading date, and although some genotypes begin with anthers starting to shed their pollen in the floret cavity, generally the anthers extrude from the floret, and are visible for scoring. The most distal florets below

and above the center may have poorly formed anthers or be sterile. The well-developed florets of central spikelet are more representative and used to accurately assess anthesis date (Simmons and Crookston, 1979).

1.4. Wheat Plant Height

Plant height is an important agronomic trait in hybrid wheat seed production and in commercial hybrid wheat field because it is believed that taller males will better pollinate females (pollen flows downward due to gravity; Boeven et al., 2016; Garst, 2017). Plant height in commercial fields is important because taller plant height increases lodging, which reduces grower acceptance, grain yield components and end-use quality (Griffiths et al., 2010).

The introduction of reduced plant height alleles (*Rht-B1b* and *Rht-D1b*) in wheat has required a new perspective on the plant height of the parental lines for hybrids (Hedden, 2003). Over several decades, those major dwarfing genes, which were the basis of the Green Revolution, have been used widely to improve lodging resistance, harvest index, and ultimately regulate total biomass production and yield stability by a substantial reduction in height (Griffiths et al., 2010).

In research by Boeven et al. (2016), two major genes *Rht-B1b* and *Rht-D1b* were highlighted to be responsible for reduction in both plant height and anther filament length that affected anther extrusion rate and pollen mass negatively. However, this research was contradicted by (Okada et al. (2021) who using European winter wheat germplasm, found the presence of the *Rht-D1b* allele was associated with large anthers and increased AE, and did not reduce filament length. The effects of these two major semi-dwarfing genes on

plant productivity and on plant height were similar in winter and spring wheat cultivars (Gent and Kiyomoto, 1997). Among U.S hard winter wheat germplasm, *Rht-B1b* allele is more frequent allele compared to *Rht-D1b* allele (Guedira et al., 2010).

1.5. Wheat Grain Yield

The improved grain yield of hybrid wheat is the primary reason that wheat growers would purchase hybrid wheat seed. The cost and availability of hybrid wheat seed which is determined by the difficulty of production and the amount of seed. A clear understanding of the agronomic traits that impact grain yield and seed production is necessary. Seeding rates will affect the amount of hybrid seed needed to plant commercial fields (an input cost for growers), hence also determines the viability of the commercial hybrid industry.

Hybrid wheat grain yield is a complex trait which is used to measure heterosis. Heterosis can lead to a 20% yield improvement in superior hybrids compared to the best commercial cultivar (Burgueño et al., 2008; Gowda et al., 2012; Longin et al., 2012). Moreover, although high grain yield is considered as one of the basic criteria for hybrid selection in many breeding programs, factors such as genotype, environment, heritability, and management practices alter yield parameters directly or indirectly, making it hard to predict how parental grain yield will affect the grain yield of resulting hybrid (Zhao et al., 2015).

Boeven et al. (2008) found that AE in male lines as positively correlated with hybrid seed yield on female lines in the crossing blocks. In a study using CIMMYT elite spring wheat accessions, it has been determined that traits such as AD, kernel size, biomass are associated with grain yield genetic gain (Lopes et al., 2012). Although semi-dwarf lines

carrying reduced height plant genes have been reported to increase plant grain yield (Peng et al., 1999; Hedden, 2003), according to studies done by Xiao et al. (2012) and Tadesse et al. (2010), plant height and number of tillers also had direct positive associations with total grain yield.

In the trials established to monitor cross pollination success between 2014-2015, Garst (2017) indicated that correlations between male plot anther extrusion rate and female plot seed yield were not statistically significant. This low correlation was caused by the asynchronous flowering of male and female lines. The highest hybrid seed production plot yields were observed in female lines pollinated by male lines with high AE (score 5.0 or above) lines with synchronous flowering (Garst, 2017).

1.6. Wheat Lodging

Lodging is described as the phenomenon of the plant shoot displacement from its vertical stance to a different angle. In severe lodging, the plant is laying (horizontal) on the ground. Lodging is affected by high plant densities, sowing date, sowing depth, irrigation procedures, high fertilizer (especially nitrogen) applications, diseases, insects, and extreme weather conditions such as heavy rain, wind, or hail (Foulkes et al., 2010). Two common types of lodging are stem lodging and root lodging which are caused by bending or breaking of the basal stem internodes and root anchorage failure respectively. Lodging was reported to have a negative correlation with grain yield by Berry et al. (2012) indicating that lodging at an angle of 45° from the perpendicular position could result in the approximately 20% reduction in grain yield. As the angle from vertical position increases, serious yield losses have been detected since the plants cannot benefit from sufficient

photosynthesis and air circulation (Berry et al., 2003). Severe lodging can cause yield loses of up to 80% and decrease end-use quality (Foulkes et al., 2010). In addition, lodged wheat has reduced photosynthetic activity and often a more conductive environment for diseases (especially fungal diseases) and insects. Hence lodging is a concern in both seed production and commercial hybrid fields (Berry and Spink, 2012).

As lodging effectively reduces plant height, lodging resistance before pollination is important in male parental lines (De Vries, 1972). Lodging resistance is also important in female parental lines for higher seed yield. Since plant height was reported to be negatively correlated with lodging resistance (Allan, 1986), to strengthen the plant's standing power, and to decrease the basal internodal length (Tripathi et al., 2003), introgression two major dwarfing genes *Rht-B1b (*formerly *Rht1*) and *Rht-D1b* (formerly *Rht2*) have been widely used to facilitate shorter cultivars since Green Revolution (Hedden, 2003). Significant negative correlations between plant height and lodging were observed in several studies indicating that shorter cultivars are less prone to lodging (Curtis & Halford, 2014; Navabi et al., 2006). Conventional approaches to evaluate lodging are visual assessment of the population, however, visual assessments may be subjective, confounded, deceptive, and expensive (Berry et al., 2003).

1.7. Genetic Tools for Understanding Traits

Recombinant inbred lines (RILs) are derived by selfing progeny developed by crossing two genetically distinct homozygous lines (Jebreen et al., 2019). They are excellent tools for understanding the underlying genetics of complex traits since RILs are genetically stable (inbred) and can be replicated within and over environments to

understand the effects of environment and how genotypes interact with the environment (Crow, 2007; Dixon, 1993). Recombinant inbred lines from a bi-parental population derived without selection (as would occur in single seed descent breeding) should have equal representation of the parental genomes without masking effects of heterozygosity (Fresh and Melchinger, 2007).

Double haploids (DHs) are obtained by spontaneous or artificial chromosome doubling methods of haploid plants. Double haploids can significantly shorten a breeding and cultivar development timelines compared to conventional breeding methods such as pedigree selection, bulk, and single seed descent (SSD) (Knox et al., 2000). Doubled haploids are very similar to RIL populations with the exception that DHs have fewer opportunities for genetic recombination that occurs during selfing thus their linkage blocks are larger. Double haploids accelerate the creation of pure homozygous lines from cultivars with any degree of heterogeneity in one generation were created via androgenesis (anther/microspore culture), gynogenesis (ovary/megaspore culture), or wide hybridization (Kim and Baenziger; 2005; Niu et al., 2014). The induction of double haploids via wide hybridization between wheat genotypes and maize (*Zea mays* L.) was developed by Laurie and Bennett (1986). The wheat x maize hybridization approach has been improved and is currently used in the development of many new wheat cultivars and mapping populations.

1.8. Statistical Tools to Examine the Role of Genetics and Environment

As G x E interaction is a determinative parameter in the phenotypic and genotypic expression of the traits, phenotypic data must be supported by the calculation of genetic values using best linear unbiased estimates (BLUEs) in early-segregating populations of

wheat (Henderson, 1975). Additionally, one of the most common approaches to facilitate selection accuracy in the improvement of agronomic traits is principal component analysis (PCA). PCA has a significant role in identifying linear combination of original, independent, and uncorrelated variables by limiting the number of variables into fewer components (Dhanda, 2018).

In this context, the estimation of variance components such as restricted maximum likelihood (REML), and BLUEs values are needed for increasing selection accuracy and improving selection efficiency (Henderson, 1975; Resende, 2016). In the present study, we evaluated different repeatability and estimates using REML and BLUEs based on contrasting environments and predict potential correlations among selected traits influencing hybrid seed production. Also, the study's aim was to guide breeders with estimates of the interaction of genes in segregating populations, thus allowing a more repeatable phenotypic selection of lines with better AE that could be combined to create heterotic groups for hybrid wheat breeding.

2. INTRODUCTION

Increasing genetic gains in wheat (*Triticum* spp.) has become an integral part of numerous hybrid and cultivar wheat breeding programs to meet the demand of an increasing global population which is expected to reach approximately 10 billion people by 2050 (Whitford et al., 2013). Correspondingly, food insecurity is also projected to increase in many regions. Developing hybrid wheat better adapted to climatic challenges and major enhancements in wheat grain yield combined with introgression of multiple resistance genes are sustainable strategies for increasing food security (Easterly et al.,

2019). There are number of steps and needs to create hybrid wheat. Specifically, you must (1) create heterotic pools to maximize genetic progress and identify high yielding hybrids, and (2) develop methods for enhanced cross pollination in a naturally self-pollinated crop to create affordable hybrid seed.

A successful hybrid wheat program depends on understanding the male and female characteristics and spike morphology and their role in hybrid seed production (Whitford et al., 2013). An ideal male (pollinator) line to be used in hybrid seed production must extrude anthers that shed pollen from a vertical (no lodging) stem and be taller than female plant to facilitate pollination of a receptive female floret (De Vries, 1972). Also, the anthesis date of the male line and the extruded stigmas and open (syn. gape) florets of female need to be synchronized to enhance cross pollination in a normally self-pollinated wheat plant. The female plant normally would reach anthesis slightly earlier than the male line, however, because the female line is male sterile, the florets will open to receive pollen a few days later than the expected female anthesis date (Stoll, 2019). In this framework, the male pollinator line should reach anthesis date slightly after the male-sterile female plants.

Returning to the important male characteristics, anther extrusion (AE) is visually easy to measure but has been reported as a genetically complex trait (Skinnes et al., 2010; Garst, 2020). Also, evaluating AE is the first step to identify a male ideotype for hybrid seed production (Boeven et al. 2016; Buerstmayr and Buerstmayr 2015). Anther extrusion must be combined with appropriate anthesis dates and physiological traits such as the length of the pollen shedding period and plant stature respectively.

The lack of knowledge about the complex underlying genetics of AE may be in part due to the use of diverse association mapping panels in most previous studies (Muqaddasi et al., 2019; Skinnes et al., 2010). Using biparental populations of homozygous lines between excellent and poor AE parents may allow a better understanding of the genes in those parents that affect AE. There are two common ways to create biparental inbred populations; by selfing, using single seed descent to develop recombinant inbred lines (RILs) or by using doubled haploid techniques to create a doubled haploid (DH) population (Muqaddasi et al., 2019). The main advantage of using a DH population is that all individuals are expected to reach complete homozygosity rapidly in one generation (development faster than RILs) with no residual heterozygosity (Tadesse et al., 2019). Considering quantitative parent-specific agronomic traits, RILs and DHs will allow replicated testing of a segregating population in multiple environments to estimate the effects of the environment, genotype, and genotype by environment (G x E).

The objectives of this study were to (1) phenotype anther extrusion (AE) together with selected important agronomic traits [anthesis date (AD), plant height (PH), lodging (LODG), and grain yield (GYLD)], (2) determine roles of genotypes, environment, and genotype x environment interactions for these traits, as well as determine their relationship to each other. Finally, based on genetic tools used, and (3) to identify the best way to select for AE and these related agronomic characteristics in different environments for which genetic variation in historical data has been noted.

3. MATERIALS AND METHODS

3.1. Plant Material

The basis of this study was a double haploid (DH) population consisting of 174 lines (hereafter referred to as (FreeCamDHs) derived from a cross between the inbred cultivars 'Freeman' (syn. 'NE06545'; Baenziger et al., 2014) and 'Camelot' (Baenziger et al., 2009; Table 3). Freeman was chosen because it has excellent AE while Camelot was chosen because it has very poor AE (Figure 1). These two parental lines are both hard red winter wheat. Freeman and Camelot are both taller, semi-dwarf cultivars that tend to have slightly later anthesis dates (https://cropwatch.unl.edu) and were released cooperatively by Nebraska Agricultural Experiment Station and the USDA-ARS. The progeny of this cross could be potential male pollinator lines.

The DHs were developed using the wheat by maize (*Zea mays* L.) DH system in cooperation with KWS, Inc Einbeck, Germany. In addition to the 174 DHs, six line were added as comparison and check cultivars: Freeman (parent line with high AE), 'SD05W018' (previously identified with high AE), 'TAM107' (previously identified with moderately high AE, acceptable as a male line), 'NI15713' (previously identified with moderately high AE, acceptable as a male line), Camelot (parent line with low AE) and 'Pete' (previously identified with low AE) for a total of 180 genotypes (Garst, 2020).

3.2. Field Experiment Design

The field experiments consisting of the 180 lines described above were grown in three environments. All experiments were planted in plots that consist of 5 rows, 23 cm apart and 3 m long using a Wintersteiger Rowseed Planter (Salt Lake City, U.S.A.). In 2019-

2020, the experiment was planted at the University of Nebraska Lincoln Havelock Farm in Lincoln, NE (40º51’22.5” N, 96º36’28.0” W) using an augmented design with single replicate of DHs and four check cultivars, and five replications of the two parental lines (hereafter referred to as 2020L). This design was necessitated by the limited seed of the DH population. In 2020-2021, the experiment was planted at the Havelock Farm at the Havelock Farm (40º51’30” N, 96º36’51.5” W, hereafter referred to as 2021L) and the University of Nebraska Eastern Nebraska Research and Extension Farm at Mead, NE (hereafter referred to as 2021M) using an alpha lattice design (Agrobase Gen II® Software [Agronomix, Inc. Winnipeg, Canada]) with two replications of 180 lines and an incomplete block size of 5. Those experimental locations were selected based on different climatic parameters and, also for accessibility to evaluate the genotypes every other day during anthesis.

The plots at Lincoln in both years were sprayed to control fungal diseases at flag leaf (Feekes growth stage [GS] 9) with Twinline® (pyraclostrobin, [2-[[[1-(4- chloropheny)-1H-pyrazol-3-yl]oxy]methyl]phenyl]methoxy-, methyl ester), metconazole, 5-[(4-chlorophenyl)methyl]-2,2-dimethyl-1-(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol, BASF Corporation, NC, USA) at the recommended 657 mL ha^{-1} and at anthesis (Feekes GS 10.5) with Caramba® [metconazole, (5-[(4-chlorophenyl)methyl]-2,2-dimethly-1-(1H-1,2,4-triazol-1-ylmethyl) cyclopentanol], BASF Corporation, NC, USA) at the recommended rate of 1170 mL ha^{-1} to suppress Fusarium head blight (Andersen et al., 2014; Wegulo et al., 2015). Fungal diseases were minimal at Mead in 2020/21, hence none of the data were affected by fungal diseases in this study.

3.3.Phenotypic Data Collection

For each experiment, the following traits were measured: anther extrusion scored on a 1-9 scale with 1 being least extruded [e.g. the anther not visible outside of the flower or only the tip of the anther barely visible between the lemma and palea], 2-3 being low AE, 3.5 to 5 being intermediate, 5.5-6.5 being good, 7-8 being very good (Figure 1) and 8.5-9 [all of the anthers clearly outside of the floret] being best for AE (Muqaddasi et al., 2019). Personal observations indicated that extruded anthers may be visible for several days, but wind and heavy rain can blow or wash away the extruded anthers: thereby, affecting the reliability of visual observation. To avoid this concern, we made our observations in the morning before the wind increased. Usually, only a single assessment was needed to represent the average of the plants in each plot. However, in some plots, usually those with anthers that were "trapped" and poorly extruded, or had a later anthesis date, visual assessment was done over several days. All AE measurements on plots in the population were reevaluated for accuracy, and extreme/odd values in the data were eliminated, allowing for a more consistent visual evaluation process.

Anthesis date was the date (in Julian days) when 50% of the spikes within a plot had extruded anthers. Similar to AE, AD, which varied with genotype, was measured over days. This approach was practical and rapid for the 7-10 days that anthesis occurred for the earliest and latest genotype in all environments. If the anthers have matured in the floret without being extruded, anthesis date was estimated by pulling the lemma and palea apart to see the color of the anthers. A further aid to know when to measure anthesis date was that anthesis usually occurred in less than seven days after full head emergence. In the

2019/20 growing season, anthesis date values were taken from a single location (Lincoln, NE) and from a single replication augmented design. In the 2020/21, the plants at the Mead started anthesis 7-10 days later than at Lincoln, and the observations in all locations were completed in a total of 14 days.

Plant height (PH) was measured in cm from the ground to the tip of the spike excluding awns). Plant height was measured on fully grown plants (at least 10 days after AD). Plants representing the population were chosen from the center of the plots. A single average value was recorded for each plot using the Field Book application (Rife & Poland, 2014), and synchronized with Agrobase Gen II® Software, allowing the data to be digitized for future statistical analysis.

Lodging (LODG) was scored on a 0-9 scale with 0 meaning no plants were leaning more than a 45-degree angle and 9 meaning 90-100% of the plot was leaning more than a 45-degree angle. As mentioned previously diseases were controlled or absent, so differences in lodging were due to weather conditions, the genotypes, and G x E interactions.

Plot grain yield (GYLD), measured by harvesting all the rows in the plot using a Zurn 150 combine harvester (Hohebuch, Germany) and converted to kg/ha. Harvest occurred when the latest genotype was mature, and the grain moisture content was between 13 and 15% to avoid yield loss due to mechanical damage. The plots matured rapidly over a five-day period. During grain yield harvest, the main obstacle was lodging, and severe lodging made grain harvesting impossible in 2020/21 at Lincoln. Seed obtained from each harvested plot were cleaned and weighed after harvesting to estimate grain yield.

3.4. Statistical Analysis

The type 3 analysis of variance (ANOVA) was conducted for the full model using genotypes as random and checks as fixed effects to analyze the augmented design grown as single replication at Lincoln environment in 2020 (Supplemental Table S1). Data were analyzed using a mixed model analysis of variance using PROC MIXED in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Analysis of variance for the check genotypes (Freeman and Camelot) was used to estimate error variance. The model is as follows:

$$Y_{ijkl} = \mu + \beta_i + C_j + \varepsilon_{ijk}$$

Where β_i is the random effect of the i^{th} incomplete block (0, σ^2_{Iblock}), C_j is the fixed effect of the j^{th} check genotype, and residual error (ε_{ijkl}: 0, σ^2_{error}).

This model was extended to analyze the 174 remaining DH and four biological check genotypes (TAM107, NI15713, SD05W018 and Pete) based on Wolfinger et al. (1997) and Federer (2005). Genetic variance (σ^2_g) was estimated using the random effects of genotype. Best linear unbiased estimations (BLUEs) were calculated using the above model with genotypes considered as fixed effects. The BLUEs of double haploid genotypes were used to calculate Pearson's correlation coefficients over three different environments in 2020 and 2021.

For the 2021 lattice designs, the incomplete blocks were groups of five in which genotypes were randomly assigned for each replication and environment. Analysis of variance (ANOVA) was conducted where locations, years and checks were treated as fixed effects, and blocks in nested location and year, genotype, genotype x location, genotype x year, and genotype x location x year were considered as random effects. Descriptive

variance components for anther extrusion and agronomical traits were estimated by using restricted maximum likelihood method (REML) assuming a full of random model in SAS software Version 15 (SAS Institute, Inc., Cary, NC, USA).

The following formula gives the statistical model for the incomplete block design (lattice) conducted for single experiments.

Note: For the traits where the relative efficiency is 100%, the analysis was performed as randomized complete block design (RCBD) for two replicated single experiments at 2021L and 2021M.

$Y_{ijkl} = \mu + \beta_i + G_{jk} + \varepsilon_{ijk}$, we assumed that where $e_{ijkl} \sim \mathcal{N}I\ (0, \sigma^2)$ and $\sigma^2 = \sigma^2 \forall I$,

where μ indicates overall mean of all genotypes, β_i is the random effect of the ith incomplete block $(0, \sigma^2_{Iblock})$, G_{jk} is the fixed effect of genotypes at jth location and kth replication, and ε_{ikl} is residual error $(\varepsilon_{ikl}: 0, \sigma^2_{error})$.

The randomized complete block design (RCBD) was used to combine the two trials in 2021 using the following equation:

$Y_{ijkl} = \mu + l_k + \beta_{ik} + G_j + Gl_{jk} + e_{ijk}$, we assumed that where $e_{ijk} \sim \mathcal{N}I\ (0, \sigma^2)$ and $\sigma^2 = \sigma^2 \forall I$,

Where Y_{ijk} is the observation on the ith block $(0, \sigma^2_{block})$, at jth location and kth replication, μ indicates overall mean of all genotypes, β_i is the random effect of the ith block $(0, \sigma^2_{block})$, G_{jk} is the fixed effect of genotypes at jth location and kth block, l_j the effect of jth location in kth, Gl_{ij} indicates G x E interaction on ith incomplete block at jth location, and e_{ijk} is the error for the residual $(\varepsilon_{ikl}: 0, \sigma^2_{error})$.

3.5. Broad Sense Repeatability (R^2)

Repeatability can be used as a proxy for heritability (Wolak et al., 2012). Repeatability estimates were calculated based on the variance components of individual years and locations, while the ANOVA of the combined over environments analysis were used for estimating broad-sense repeatability values (Bernardo, 2020). For the repeatability equation (2020L, 2021L and 2021M), there is no G x E variance, and the value of e is one.

Broad sense heritability estimates were calculated for traits and populations using the equation for each trait observed in 2021L and 2021M. The formula is as follows:

$$\text{Repeatability } (R^2) = \frac{\sigma^2\text{genotype}}{\sigma^2\text{phenotype}} = \frac{\sigma^2\text{genotype}}{\sigma^2\text{genotype} + \frac{\sigma^2\text{genotype} \times \text{e}}{\text{r}} + \frac{\sigma^2\text{error}}{\text{r} \times \text{e}}}$$

where, σ^2genotype indicates variance component for genotypes, σ^2phenotype indicates variance components for phenotypes, σ^2error indicates variance components for error, r is the number of replications and e is the number of environments.

3.6. Pearson's Correlation Coefficients

The Pearson's correlation coefficients (r) were calculated for the five traits measured having approximately normal distributions. The BLUEs of DHs were used to generate Pearson's correlation coefficient to measure the significance and direction of linear relationship between pairs of the proxy and agronomic traits using JMP (SAS Institute, Inc., Cary, NC, USA) at 2020L, 2021L and 2021M.

3.7.Principal Component Analysis and K-means Clustering

A linear transformation of the best linear unpredicted estimations (BLUEs) was obtained creating five principal components PC_1 to PC_5 were extracted from three

experiments (2020L, 2021L and 2021M) to investigate the explained variation in the population. The biplot package in RStudio (RStudio, PCB., Boston, MA, USA) was used to demonstrate the position of each variable. A two-dimensional biplots were generated using both PC_1 and PC_2 investigating the DH population phenotypic performance over three experiments.

Also, a K-means clustering analysis was conducted through the GAP statistics distance matrix using k-means [stats package] in RStudio (Tibshirani et al., 2001) to validate the findings of PCAs as well as to understand how anther extrusion (AE), anthesis date (AD), plant height (PH), lodging (LODG) and grain yield (GYLD) phenotypically differed from each other for performing a selection among 174 DHs.

4. RESULTS AND DISCUSSION

Summary of statistics using 180 lines including 174 DHs and six checks:

In 2020, we did not identify significant genotype effects in the DH population for AE, AD and LODG. However, the parent genotypes used as checks were significantly different for AE ($p<0.05$). Genotypic variance for GYLD were significant for the DH lines ($p<0.05$) and nearly significant for the parental lines (Supplemental Table S1.1). The main reasons why genotypes for many traits in this population were not statistically significant were (1) this population consisted of a single replication and lacked statistical power, (2) for some traits, the environment did not allow the expression of some traits (e.g. LODG).

In 2021, significant differences ($p<0.01$) were identified among genotypes for all traits measured in both environments (AE, AD, PH and LODG) using a combined ANOVA (2021L and 2021M). The genotype x environment interaction was significant ($p<0.05$) for

AE and AD, but not for PH and LODG. GYLD could not be analyzed over environments due to severe lodging that prevented harvest at Lincoln, 2021 (Supplemental Table S1.2).

Considering the two 2021 environments separately, the ANOVAs found significant differences among genotypes for AE, AD, PH and LODG ($p<0.05$) at 2021L. Similarly, the single environment ANOVA found significant differences among genotypes for AE, AD, LODG and GYLD ($p<0.05$) and PH ($p<0.01$) at 2021M (Supplemental Table S1.1).

Genotypic performances of 180 lines based on the best linear unbiased estimations (BLUEs):

In 2020L, the mean performance of AE was (5.1) lower than the means obtained from 2021L and 2021M (5.66 and 5.64 respectively) in 2021 indicating that genotypic performance for AE was affected by the environment (Supplemental Table S1.1). Likewise, the mean performance of AD decreased from 148.9 (Julian days) in 2020L to 141.9 and 142.5 in 2021L and 2021M respectively suggesting that AD was affected by environments. The genotypic means for PH also differed over environments (2021L and 2022M) by decreasing from 103.2 to 99.6 cm while LODG had the mean increasing from 3.1 in 2020L to grand mean of 4.0 obtained from combined analysis of 2021L and 2021M. However, the 2021 combined results indicated that the genotypes responded similarly to the environments due to the absence of genotype x environment interaction for both PH and LODG.

The BLUEs for AE for parental cultivar Freeman had consistent values ranging from 6.0 to 6.6, while Camelot known for its poor anther extrusion had mean AE BLUEs ranging from 3.5 to 4.0 over three environments (Supplemental Table S1.1). Additionally, among

check genotypes (SD05W018, TAM107, NI15713 and Pete), SD05W018 had highest BLUEs ranging from 8.0 to 8.7, TAM107 and NI15713 had means ranging from 5.0 to 5.5 and 5.5 to 7.0 respectively at three different environments, while "Pete" gave one of the lowest BLUEs ranging from 3.7 to 3.9. These results were similar to our previous results (Garst, 2017; Garst, 2020) and indicated that these environments were representative of eastern Nebraska.

In the single replicate experiment observed in 2020, more than 50% of the genotypes had 5.0 (1-9 scale) or higher BLUEs for anther extrusion. About 85 percent of BLUEs of the same population from 2021L and 2021M had a mean value of 5.0 or higher (Supplemental Table S1.1). The individual location results indicated that the selection of candidate pollinator lines should not be done in 2020L due to the absence of genotypic differences among DHs for AE, AD and LODG. The anthesis date of the 180 lines grown at 2020L was also later than the DH populations grown at 2021L and 2021M which may have affected the results. The main reason for this difference in anthesis date between years was the early high temperatures experienced in 2021 which hastened anthesis. From those average values, parental lines that could flower at appropriate times for hybrid seed production were identified and could be for selected male pollinator AE and AD.

Summary of statistics for only DH populations developed from Freeman x Camelot:

While the results from 174 DH lines and six checks are important, only 174 DH lines from the Freeman x Camelot cross were used to understand the genetic variation of AE, AD PH, LODG and GYLD. As mentioned earlier (Table 1), it was difficult to combine the 2020L data with 2021L and 2021M data so only the combined analysis results (2021L and

2021M) will be discussed. However, the 2020L data can be used to support the conclusions from the 2021 analyses. As expected, the combined ANOVA found significant differences ($p<0.001$) among DH genotypes for AE, AD, PH and LODG (Table 1). Similar to our results from 180 lines, the genotype-by-environment interactions were significant for AE and AD ($p < 0.05$), but not for PH and LODG. GYLD was lost in 2021L and not included in the combined analysis. A reason why plant height observed in DHs seemed be more consistent over different environments was that DH population was derived from two semi-dwarf parental cultivars Freeman x Camelot both carrying *Rht-B1b* which leads to short plant stature.

The population mean, range, standard deviation and frequency distribution for each trait were portrayed using violin plots (Figure 2). The BLUEs of all DHs for the traits measured had approximately normal distributions with high variability in the three environments suggesting that no major gene effects in the DH population were phenotypically identified.

The best linear unpredicted estimations (BLUEs) showed approximately normal distributions with low (AD, PH), moderate (GYLD), and high (AE, LODG) coefficient of variations (CVs) for the traits measured (Figure 2). Accordingly, using categorical scales for AE (1-9) and LODG (0-9), may have explained their high CVs. On the other hand, AD had the lowest CVs ranging from 0.8 to 1.04, followed by of PH and GYLD having CVs were below 10% (Supplemental S1.1).

In the combined analyses results comparing 2021L and 2021M populations, similarly the high CVs were largely driven by categorical scales for both AE and LODG

(Supplemental TableS1.2). It was considered that using a bi-parental DH population derived from two parental lines potentially carrying semi-dwarfing genes *Rht-B1b* could be a primary reason for obtaining low CV values for PH in addition to the accuracy of measurement and uniformity of the plots conducted. Even though significant phenotypic diversity was detected for PH and LODG population, the G x E interaction was not significant on genotypic performance suggesting that the population responded similarly to the environments.

Genotypic performance was estimated using the best linear unbiased estimations for three different double haploid trials covering only 174 DH segregations from each experiment. A few genotypes were consistently high or low performers in three different double haploid populations grown at 2020L, 2021L and 2021M (Table 2). For example, the anther extrusion performance of 'FreeCamDH174' and 'FreeCamDH40' was above the mean and consistently high (excellent AE), while the BLUEs for 'FreeCamDH3' and 'FreeCamDH173' were below the mean indicating the genotypes were poor extruders in each environment.

The BLUEs for AD showed that 'FreeCamDH5' and 'FreeCamDH46' had latest ADs over three environments. It was expected to observe some inconsistency in the performance of genotypes in AE and AD traits, where G x E interaction is important, but much of the G x E was due to changes in magnitude and not due to charges in order (cross-over interactions). Hence this research identified that were several male pollinator candidate lines with appropriate AD over three distinct environments.

In the combined analysis results, the G x E for the PH and LODG traits was not significant indicating a similarity in the performance of each genotype expressed in the double haploid population over two environments. To illustrate; the genotypes labeled ‘FreeCamDH56’, ‘FreeCamDH125’ and ‘FreeCamDH148’ were as tallest semi-dwarf segregants over three experiments. ‘FreeCamDH30’, ‘FreeCamDH70’ and ‘FreeCamDH70’ genotypes had consistently short plant height BLUEs between 2020 and 2021. Severe lodging was observed on ‘FreeCamDH10’ and ‘FreeCamDH101’ genotypes over three environment and ‘FreeCamDH62’ had the most consistently low lodging values over three experiments (Table 2).

Considering grain yield (GYLD), the plots could not be harvested due to the extreme lodging monitored at 2021L. Although this situation caused GYLD to be excluded from the combined analysis, the single environment statistics obtained from the 2020 LIM and 2021 MD experiments revealed that the genotypes were statistically different from each other. However, the performances of the genotypes changed significantly and over the years.

Broad sense repeatability estimates for 2020L, 2021L and 2021M:

Similar repeatability coefficients were calculated for three different experiments grown between 2020 and 2021 (Supplemental Table S1.1). The repeatability values for AE were ranging low to moderately high, ranging from 0.33 to 0.63. Likewise, AD had more variable repeatability values ranging from 0.45 to 0.67 and was not as high as results reported by Sade et al. (2022). The repeatability (R^2) of the trait performance for PH and GYLD was more variable similar to AE and ranged from 0.36 to 0.69 and 0.50 to 0.67,

respectively. Lodging had the highest repeatability estimate but ranged between 0.28 and 0.82 among all traits measured.

The experiments without two replications (specifically for the 2020L augmented design) tended to have of low repeatability as would be expected when genotypic differences were not found significant for many traits (Supplemental TableS1.1). These calculated repeatability values can be considered as a proxy for the broad sense heritability values to be calculated from the over environment analyzes of the 2021 progenies at Lincoln and Mead.

Broad sense repeatability (R^2) values were estimated based for traits measured on over environments in the combined analysis results including parental lines and checks (180 lines) grown as two replications at both 2021L and 2021M (Supplemental Table S1.2). AE and AD had moderately high repeatability estimates 0.66 and 0.51 respectively. The moderately high repeatability estimates for AE were consistent with previous findings (Sade et al. 2022; Garst, 2017; Boeven et al. 2016; Skinnes et al. 2010). PH and LODG were highly repeatable ranging from 0.61 to 0.84, respectively as would be expected for the latter two traits where there were genotypic differences and a non-significant GxE. Combined analysis results revealed that the higher the GxE interaction explained, as expected, and the lower repeatability of AE and AD in 2021L and 2021M populations.

In addition, broad sense repeatability (R^2) values were estimated for FreeCamDH population (174 DHs) excluding parental lines and checks for each environment (Table 1). Accordingly, the FreeCamDH population repeatability estimates were moderately high ranging from 0.55 to 0.60 implying that the genotypic performance of the population was

partially controlled by environment and G x E for AE. Anthesis date had low to moderately high repeatability estimations (0.28 to 0.66) were calculated in single locations at FxC21L and FxC21M. The population genotypic performances were moderately and highly repeatable for PH and LODG ranging from 0.50 to 67 and 0.71 to 0.80 respectively.

Combined over location analysis revealed that the DHs were repeatability (0.62) for AE while the population genotypic performance for AD had slightly lower repeatability with 0.54 (Table 1). Similar with repeatability estimates for single environments, the FreeCamDH population were highly repeatable for PH and LODG (0.71 and 0.84) respectively (Table 1). Again, this result can be explained by PH and LODG having a non-significant GxE interactions over 2021L and 2021M.

Pearson's correlation coefficients for DHs in 2020L, 2021L and 2021M:

Pearson's correlation coefficients were calculated based on the individual trait x environment analyses comparing phenotypic performance of 174 DHs over three experiments (Figure 3A). Overall, in 2020L population, the Pearson's correlations were less applicable for 3 of 4 traits (AE, AD and LODG) as DH individuals were found to be not genetically different from each other. However, we included those correlations for completeness (Table 3a). Correlations between the combined values for the two experiments conducted as two replications in 2021 were calculated separately and given in (Figure 3B).

Both negative and positive correlations were found between AE and AD indicating that our results were different from Garst, 2017 who found using an association mapping panel that the earlier lines had higher AE scores. As a result of sudden temperature changes

(especially unexpected early high temperatures) and related stress physiology during the pre-anthesis developmental periods, the environments in this study may have affected AE such that in some years the early lines had better AE and in other environments later lines had better AE. Also, Garst, 2017 used an association mapping panel, while we use a biparental DH population which would also affect the results.

No significant relationship was detected between AE and PH. This result supported previous studies done by Garst, (2020), Steiner et al. (2019) and Baenziger et al. (2014), found that AE and semi-dwarfing allele (*Rht-B1b*) were not related, hence plant height did not affect AE (Table 3b). This result is important because it suggest that male pollinator lines of all heights can be developed.

Interestingly, the correlation using the combined data from FreeCamDHs in 2021L and 2021M revealed that anther extrusion and lodging were significantly and negatively correlated ($r= -0.39$, $p < 0.05$) (Table 3b). This result suggested that lines with higher AE appeared to have better straw strength as determined by severe lodging. Alternatively, some the FreeCamDH may have lodged at AD, making AE scoring difficult. It was difficult to make a uniform visual assessment of AE on partially or completely lodged rows. There was no negative correlation between AD and PH suggesting that taller DHs could be selected with different AD as would be needed in hybrid seed production fields.

A negative correlation ($r= -0.25$, $p < 0.05$) between LODG and GYLD at 2021M was consistent with findings reported by Berry et al. (2012) and Foulkes et al. (2010). Moreover, a significant positive correlation ($r=0.20$, $p < 0.05$) (Table 3b) between PH and LODG characteristics was consistent with the previous findings Curtis et al. (2014) and

Navabi et al. (2006) suggesting that the shorter semi-dwarf DH segregants were less prone to lodging.

The FreeCamDHs in 2021L and 2021M could not be correlated for GYLD due to severe lodging experienced at 2021L and the field was not harvested. The correlation between 2021L and 2021M suggested a negative correlation ($r= -0.22$, $p < 0.05$) between LODG and GYLD (Table 3a). Also, positive correlation observed between AE and GYLD on pollinator lines suggested that male lines can be selected that will have excellent AE for hybrid seed production on female lines (Boeven et al., 2018; Garst., 2017) and produce grain for commercial sale or seed for future hybrid seed production fields. Also, in a cytoplasmic male sterile hybrid system (Cisar and Cooper, 2002; Whitford et al., 2013) where you need the female maintainer line to be an excellent pollinator, having a positive correlation between AE and GYLD would be important.

Overall, in 2020 population, the Pearson's correlations were less applicable for 3 of 4 traits (AE, AD and LODG) as DH individuals were found to be not genetically different from each other. Additionally, non-significant GxE interactions revealed that low phenotypic differences among segregants for PH and LODG were most likely due to the biparental population and some major genes (e.g. *Rht-B1b*) (Steiner et al., 2019) being homozygous in the population.

Principal components (PCs) for three environments 2020L, 2021L and 2021M:

PC_1 and PC_2 accounted for 45.6% and 24.21% total of the variance contribution respectively (Figure 4). PC1 and PC2 were determined as favorable components on which

selection of the traits of interest can be performed as only their eigen values greater than 1, 2.2 and 1.2 respectively (Table 4).

The individual contribution of the variables of the five principal components impacted the contribution of each principal component to the total variance. According to loading values, days to anthesis (AD) contributed 38.7% of total variance while contributions of plant height (PH) had slightly lower percentage (37.8%) in PC_1. In the PC_2, the two scaled data that contributed the most to the total variation were lodging (LODG) and anther extrusion (AE) with values of 51.3% and 42.5% respectively. Additionally, in PC_3, the contribution of grain yield to total variance was high (71.38%) (Table 4).

AE and AD traits contributed positively to PC_1 while PH, LODG and GYLD had negative loadings. The second principal component had negative loading values for all traits except anther extrusion. With 0.085 and 0.045 loading factors, which were the two closest values to zero in PC_3 indicated that the contributions of lodging and grain yield to the total variation were lower than other traits.

K-Means Clustering:

The gap statistics of 174 DHs from each 2020L, 2021L and 2021M assessed visually for five traits at three environments reached the maximum level at four clusters (k=4) (Figure 5). The BLUEs of 174 DHs clustered based on anther extrusion, anthesis date, plant height, lodging and grain yield performances. The three experiments were divided into four groups having 171, 174, 101 and 76 data points based on the five traits measured and biological means were determined for each cluster (Supplemental Table S3).

According to the cluster 1, the clustered lines were less prone to lodge with late anthesis dates (Figure 5), and the clustered lines had an average lodging of 3.2 (0-9 scale) with an average anthesis date of 149 (Julian days) in 2020L. In the cluster 2, moderate lodging (an average of 4.2) was observed in 2021L, and the cluster had the tallest plant height mean having approximately value of 103 (cm) (Supplemental Table S3). The cluster 3 included lines with higher AE mean (score of 6) at 2021M than 2021L having an average of 5.6 (1-9 scale) and the highest grain yield mean was determined with an average of 4988 (kg/ha) in 2021M. Finally, in cluster 4 included lines that had severe lodging (having a mean of 6.2) with high GYLD (4804 kg/ha) suggesting that just as severe lodging could affect grain yield negatively, a high grain yield could also be a reason for severe LODG.

Overall, PCAs and K-means results suggested that bi-parental double haploid population showed very high similarity, however scaled data for both AE (1-9) and LODG (0-9) had more unexplained variability than AD, PH and GYLD as could be seen in their high CVs.

5. CONCLUSION

Our study agreed with previous studies that anther extrusion is most likely a genetically complex trait with moderately high heritability value of 0.66. AE is one of the parent-specific traits that is extremely important for male ideotypes, and visual assessment of AE is a practical and affordable way to evaluate large number of genotypes. Our study also revealed that evaluating a double haploid population derived from two distinct inbred lines phenotypically for AE was inadequate to identify any major genes controlling AE and other selected agronomic traits. Pearson’s correlation coefficient results revealed a significant

negative correlation ($r=-0.39^{**}$) between AE and LOGD suggesting that higher AE appeared to have better straw strength as determined by severe lodging. In the experiments set up in three environments, it was observed that the FreeCamDH segregants included some good pollinator candidate lines (anther extrusion of 6.0 or higher) with medium (142 Julian days) to late (149 Julian days) AD that will allow them to pollinate and synchronize with a receptive female genotype for hybrid seed production. Additionally, lines with a slightly taller average of PH (103 cm) and intermediate LODG of 4.3 which are useful for cross pollination were identified and should increase the effectiveness of high pollen dispersal in a crossing block. The results of the phenotypic analysis showed that the individuals belonging to the population differed significantly in genotypic terms, especially AE. Finally, it was possible to select for lines with good AE in single environments where the genotypes were significantly different as would be required in a breeding program. Even in environments were the statistical power to separate genotypes was lacking, lines with good AE could be identified. The phenotypic values obtained from the DH lines will become the basis for a mapping study which should help select of better male pollinator lines.

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7. SUPPLEMENTAL MATERIAL

Supplemental Table S1.1 includes the best linear unbiased estimations (BLUEs) mean, range, error variance, genetic variance, environmental coefficient of variation, coefficient of variation, and the least significant difference for traits measured (AE, AD, PH, LODG and GYLD) for three environments conducted at Lincoln in 2020 and at Lincoln and Mead in 2021 while Supplemental Table S1.2 gives the summary of statistics for over environments result combining 2021L and 2021M populations including checks and parental lines. Supplemental Table S2. showing loading values and contributions of 174 DHs to four extracted PCAs for AE, AD, PH and LODG. Supplemental Table S3. K- means clustering results based on GAP statistics subgrouping three experiments into 4 clusters. Supplemental Table S4.1 Original data showing traits measured on population conducted as single replication at Lincoln in 2020; Supplemental Table S4.2 shows original data showing observations of traits measured at Lincoln experiment conducted with two replications in 2021 and Supplemental Table S4.3 original data showing observations of traits measured at Mead conducted with two replications in 2021.

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Figure 1. Assessment of anther extrusion scored on a 1-9 scale.

Note: A. 1 being least extruded (anthers not or barely visible). B. 3.5 to 5 being intermediate (mainly anthers fully extruded, but other only partially extruded) C. 7-8 being very good (virtually every anther extruded and visible outside the floret).

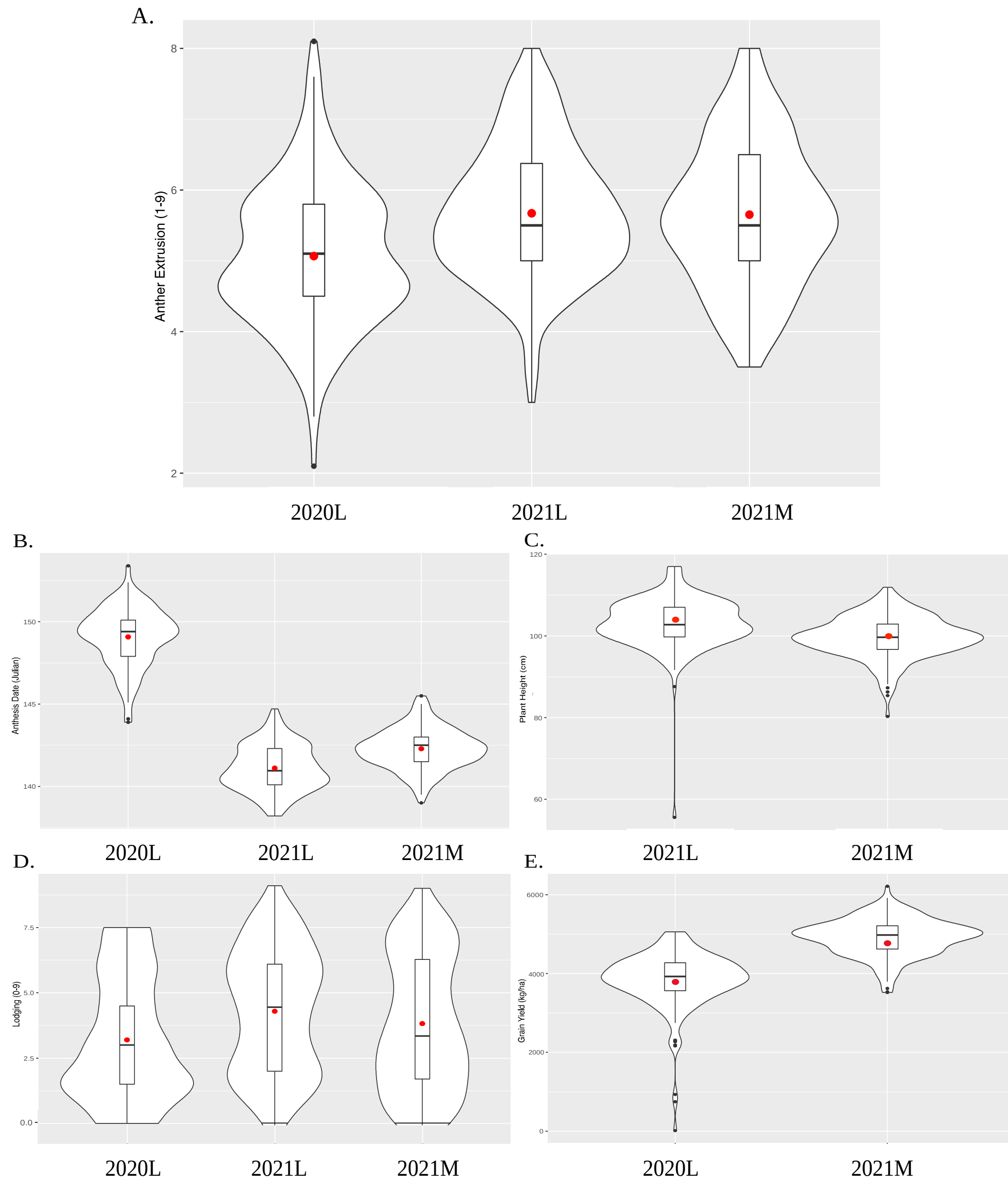
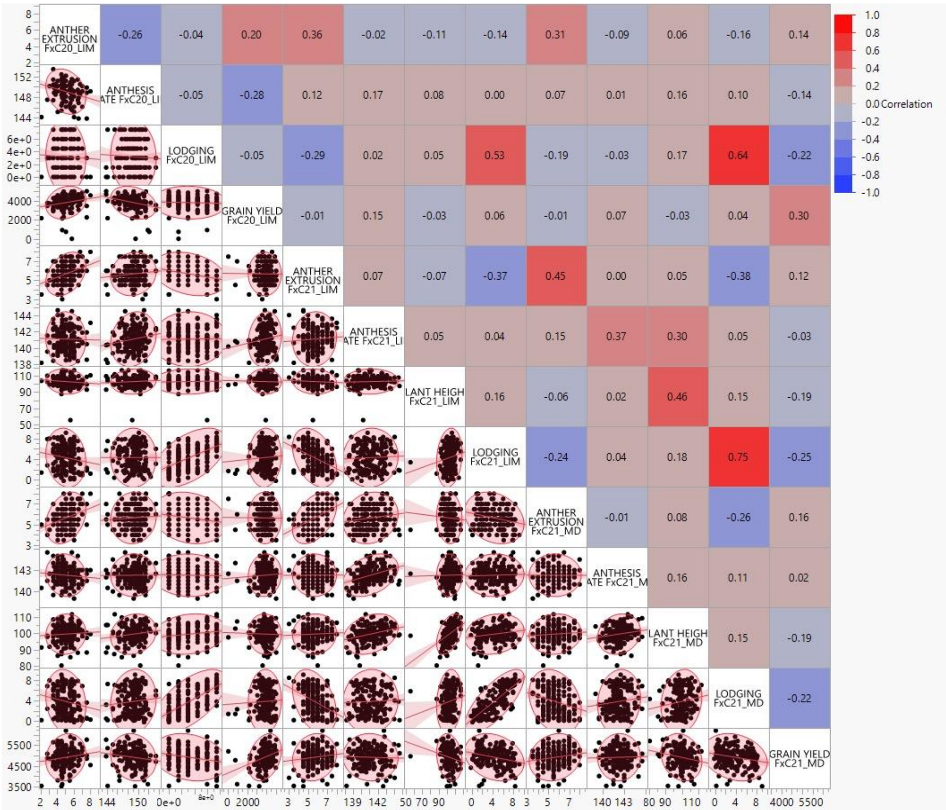


Figure 2. Violin plots showing the best linear unbiased estimators found approximately normal distributions.

NOTE: mean (red dots), standard deviation (rectangle boxes) and frequency distributions of BLUEs anthesis extrusion, anthesis date, plant height, lodging and grain yield for 174 Freeman x Camelot double haploids harvested in 2020 at Lincoln (2020L) and in 2021 at Lincoln (2021L) and Mead (2021M).

Abbreviations: A. the anther extrusion (1 [poor extruded] to 9 [fully extruded]), B. days to anthesis (in Julian Days), C. plant height (cm), D. lodging scores (0 [erect plants] to 9 [plants are horizontal with the ground], E. grain yield (kg/ha)

A.



B.

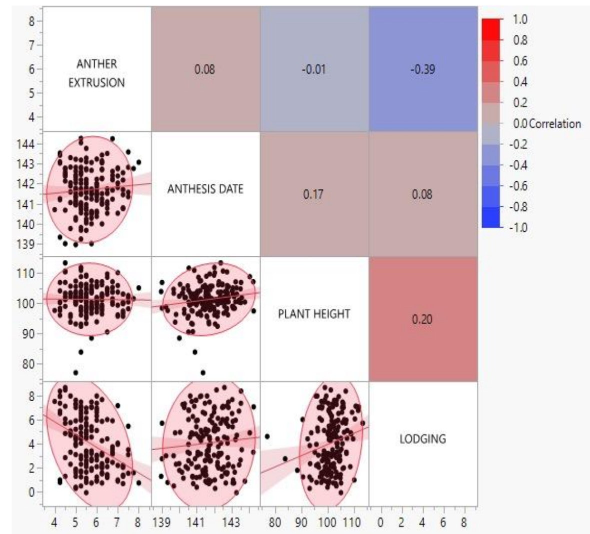


Figure 3. Pearson's correlation coefficients among anther extrusion, days to anthesis, plant height, lodging and grain yield for 174 Freeman x Camelot double haploids harvested in 2020 at Lincoln (2020L) and in 2021 at Lincoln (2021L) and Mead (2021M).

Note: A. Scatterplot matrix demonstrates the correlation among anther extrusion (1 [poor extruded] to 9 [fully extruded]), days to anthesis (in Julian Days), plant height (cm), lodging scores (0 [erect plants] to 9 [plants are horizontal with the ground], at Lincoln, 2020 (FxC20_LIM), Lincoln, 2021 (FxC21_LIM) and Mead, 2021 (FxC21_MD) respectively while B. indicates the correlation among described traits using only BLUEs of FxC21L and FxC21M.

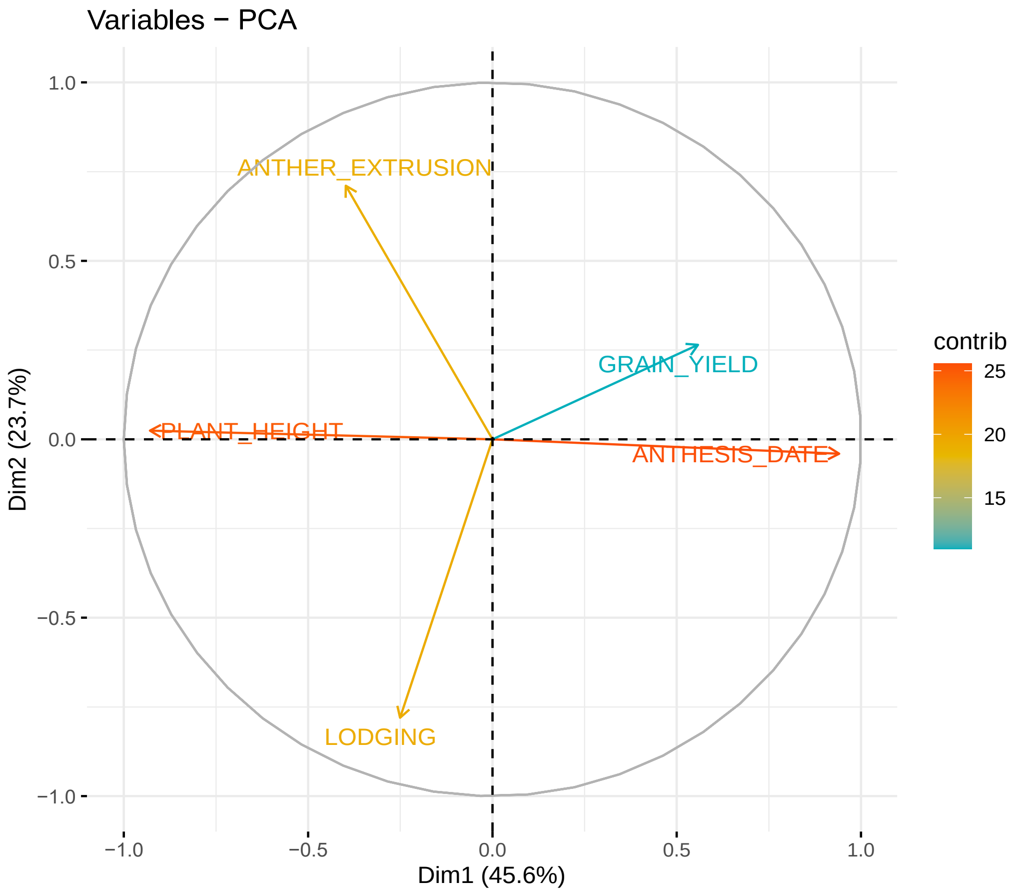


Figure 4. Principal component analyses (PCAs) of double haploid populations grown as three experiments at 2020L, 2021L and 2021M.

Note: The figure demonstrates a biplot comparing PCA_1 (Dim1) and PCA_2 (Dim2) for traits loadings indicating interactions among male and other agronomical traits.

Figure 5. K-Means clustering using GAP statistics.

Note: The figure shows K-means clustering in which 174 DHs were grouped in four clusters based on five traits measured over three environments. Cluster 1, the circles represent a late anthesis group that less prone to lodge highlighted in red; Cluster 2 (triangles), highlighted in light green clustered for a severe lodging group of tall plant stature (triangles); Cluster 3 (squares), includes a high pollen dispersal group of vertical stature (squares) in dark green and Cluster 4 (crosses), highlighted in purple.

Table 1. Summary of statistics for single and combined experiment analyses results for anther extrusion, days to anthesis, plant height, lodging and grain yield for 174 Freeman x Camelot double haploids harvested in 2021 at Lincoln (2021L) and Mead (2021M).

Summary of analysis of variance (ANOVA) and DHs trait significance results using 2021L							
Traits	Units	σ^2_{Geno}	σ^2_{Res}	σ^2_{Phen}	R^2_{DH}	LSD	D.F
Male							
Anther Extrusion	(1-9)	0.537^{***}	0.697	0.886	0.6	1.648	173
Agronomic							
Days to Anthesis	Julian	1.266^{***}	1.285	1.909	0.66	2.238	173
Plant Height	cm	13.523^{***}	26.613	26.83	0.5	10.182	173
Lodging	(0-9)	4.571^{***}	2.192	5.667	0.8	2.922	173
Summary of analysis of variance (ANOVA) and DHs trait significance results using 2021M							
Traits	Units	σ^2_{Geno}	σ^2_{Res}	σ^2_{Phen}	R^2_{DH}	LSD	D.F
Male							
Anther Extrusion	(1-9)	0.584^{***}	0.925	1.047	0.55	1.8987	173
Agronomic							
Days to Anthesis	Julian	0.421^{*}	2.17	1.506	0.28	2.908	173
Plant Height	cm	17.686^{***}	16.79	26.081	0.67	8.087	173
Lodging	(0-9)	4.980^{***}	3.933	6.944	0.71	3.914	173
Grain Yield	kg/ha	93334.65^{***}	206049.7	196359.5	0.47	895.94	173

Table 1. Continued

Combined Analysis of variance (ANOVA) using 2021L and 2021M populations grown in Lincoln and Mead respectively in 2021									
Traits	Units	μ	σ^2_{Geno}	σ^2_{Env}	σ^2_{GxE}	σ^2_{Res}	CV%	R^2_{DH}	D.F
Male									
Anther Extrusion	(1-9)	5.662	0.433***	NS	0.128*	0.8113	15.9	0.62	346
Agronomic									
Days to Anthesis	Julian	141.697	0.633***	NS	0.211*	1.7283	0.9	0.54	346
Plant Height	cm	101.531	14.869***	5.780376*	NS	21.702	4.6	0.71	346
Lodging	(0-9)	4.06	4.559***	NS	NS	3.113171	43.4	0.84	346

Abbreviations; μ, grand mean; σ^2Geno, genotypic variance; σ^2Phen, phenotypic variance; σ^2Env, environmental variance; σ^2GxE, variance due to G x E interactions; σ^2Res, error variance; CV, coefficient of variation; R^2_{DH}, double haploid population repeatability; D.F, degree of freedom for residual.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
NS, not significant at the 0.05 probability level.

Table 2. Mean, standard deviation, range, and coefficient of variation for anther extrusion, days to anthesis, plant height, lodging and grain yield for 174 double haploids harvested in 2020 at Lincoln (2020L) and in 2021 at Lincoln (2021L) and Mead (2021M).

Trait	Environments ††	Mean	Minimum	Maximum	SD	CV %	LG	HG
Anther Extrusion (1-9)	2020L	5.0	2.05	8.05	1.414	28.0	**FreeCamDH173 FreeCamDH3**	**FreeCamDH174 FreeCamDH40**
	2021L	5.6	3.0	8.0	0.835	14.7		
	2021M	5.6	3.5	8.0	0.961	17.0		
Anthesis Date (Julian)	2020L	149.0	143.8	153.4	1.264	0.8	**FreeCamDH116 FreeCamDH119**	**FreeCamDH5 FreeCamDH46**
	2021L	141.1	138.1	144.6	1.134	0.8		
	2021M	142.2	139	145.5	1.473	1.04		
Plant Height (cm)	2020L	NA	NA	NA	NA	NA	**FreeCamDH30 FreeCamDH70**	**FreeCamDH125 FreeCamDH148**
	2021L	103.3	55.5	116.9	5.158	4.9		
	2021M	99.6	80.2	111.8	4.097	4.1		
Lodging (0-9)	2020L	3.1	0	7.5	1.742	54.4	**FreeCamDH10 FreeCamDH101**	**FreeCamDH62 FreeCamDH78**
	2021L	4.2	0	9	1.480	34.4		
	2021M	3.8	0	9	1.983	51.8		
Grain Yield (kg/ha)	2020L	3836.8	14.02	5059.4	149.8	3.9	**FreeCamDH25 FreeCamDH173**	**FreeCamDH8 FreeCamDH165**
	2021L	NA	NA	NA	NA	NA		
	2021M	4924.2	3519.3	6216.1	453.92	9.2		

Abbreviations: SD, standard deviation; CV, coefficient of variation; LG, low genotype; HG, high genotype.

†† 2020L, double haploid population grown at Lincoln, 2020; 2021L, double haploid population grown at Lincoln, 2021; 2021M, double haploid population grown at Mead, 2021.

Table 3a. Pearson's correlation coefficients for anther extrusion, days to anthesis, plant height, lodging and grain yield for 174 Freeman x Camelot double haploids harvested in 2020 at Lincoln (2020L) and in 2021 at Lincoln (2021L) and Mead (2021M).

Traits † (Environments) ††	AE (2020L)	AD (2020L)	LODG (2020L)	GYLD (2020L)	AE (2021L)	AD (2021L)	PH (2021L)	LODG (2021L)	AE (2021M)	AD (2021M)	PH (2021M)	LODG (2021M)
AD (2020L)	**-0.26***											
LODG (2020L)	-0.04^{NS}	-0.05^{NS}										
GYLD (2020L)	**0.20***	**-0.28***	-0.05^{NS}									
AE (2021L)	**0.36***	0.12^{NS}	**-0.29***	-0.01^{NS}								
AD (2021L)	-0.02^{NS}	0.17^{NS}	0.02^{NS}	0.15^{NS}	0.07^{NS}							
PH (2021L)	-0.11^{NS}	0.08^{NS}	0.05^{NS}	-0.03^{NS}	-0.07^{NS}	0.05^{NS}						
LODG (2021L)	-0.14^{NS}	0.00^{NS}	**0.53****	0.06^{NS}	**-0.37***	0.04^{NS}	0.16^{NS}					
AE (2021M)	**0.31***	0.07^{NS}	-0.19^{NS}	-0.01^{NS}	**0.45***	0.15^{NS}	-0.06^{NS}	**-0.24^{NS}**				
AD (2021M)	-0.09^{NS}	0.01^{NS}	-0.03^{NS}	0.07^{NS}	0	**0.37***	0.02^{NS}	0.04^{NS}	-0.01^{NS}			
PH (2021M)	0.06^{NS}	0.16^{NS}	0.17^{NS}	-0.03^{NS}	0.05^{NS}	**0.30***	**0.46***	0.18^{NS}	0.08^{NS}	0.16^{NS}		
LODG (2021M)	-0.16^{NS}	0.10^{NS}	**0.64****	0.04^{NS}	**-0.38***	0.05^{NS}	0.15^{NS}	**0.75****	-0.26^{NS}	0.11^{NS}	0.15^{NS}	
GYLD (2021M)	0.14^{NS}	-0.14^{NS}	**-0.22^{NS}**	**0.30^{NS}**	0.12^{NS}	-0.03^{NS}	-0.19^{NS}	**-0.25***	0.16^{NS}	0.02^{NS}	-0.19^{NS}	-0.22^{NS}

Table 3a. Continued

Note: Correlation coefficient results top, and bottom belong to 2020L, 2021L and 2021M populations, respectively.
† AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield.
†† 2020L, double haploid population grown at Lincoln, 2020; 2021L, double haploid population grown at Lincoln, 2021; 2021M, double haploid population grown at Mead, 2021.
*, **, Significant at the 0.05 and 0.01probability level, respectively. 'NS' not significant at any probability level.

Table 3b. Pearson's correlation coefficients for anther extrusion, days to anthesis, plant height and lodging for combined analysis of 174 DHs in 2021.

Traits †	AE	AD	PH	LODG
AD	0.08 ^{NS}			
PH	-0.01 ^{NS}	0.17 ^{NS}		
LODG	**-0.39** *	0.08 ^{NS}	**0.20** *	

† AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging.
* Significant at the 0.05 probability level. 'NS' not significant at any probability level.

Table 4. Loading values and percentage contribution of anther extrusion, days to anthesis, plant height, lodging and grain yield to principal components (PCs) for 174 Freeman x Camelot double haploids harvested at Lincoln in 2020 and in 2021 at Lincoln and Mead.

TRAITS	EIGEN VECTORS					
	PC_1		PC_2		PC_3	
	Loading values	Contribution of variable (%)	Loading values	Contribution of variable (%)	Loading values	Contribution of variable (%)
AE	-0.3981009	6.94866691	0.71061355	42.5764125	-0.1512938	2.91567662
AD	0.94056233	38.7873682	-0.0401873	0.13616958	0.1031723	1.35588671
PH	-0.9293208	37.8657394	0.0242376	0.04953148	-0.1715442	3.74842947
LODG	-0.2507937	2.75770967	-0.78033	51.3403343	-0.4021357	20.5988255
GYLD	0.55777343	13.6405159	0.26447513	5.89755217	-0.7485887	71.3811818
Eigenvalue		2.28078763		1.18603608		0.78505995
Proportion of Variance		45.6157526		23.7207216		15.7011989
Cumulative Proportion		45.6157526		69.3364742		85.0376731

Abbreviations; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield; PC, principal component.

Supplemental Table S1.1. The list of 180 BLUEs consist of 174 DHs means from three DH including parental lines (Freeman and Camelot) and check cultivars (SD05W018, TAM107, NI15713, Pete) conducted as three experiments, augmented design in 2020 at Lincoln (2020L), and alpha lattice-RCBD designs in 2021 at Lincoln (2021L) and Mead (2021M).

TRAIT	**MALE**			**AGRONOMIC**									
NAME	Anther Extrusion			Days to Anthesis			Plant Height		Lodging			Grain Yield	
LOCATION	LIM	LIM	MD	LIM	LIM	MD	LIM	MD	LIM	LIM	MD	LIM	MD
YEAR	2020	2021		2020	2021		2021		2020	2021		2020	2021
FreeCamDH1	5.6	6.5	7	149.85	143.71	141.5	103.02	104.88	4.5	5.6	6.2	3898.3	5255.6
FreeCamDH2	5.6	6.5	7	147.85	142.82	142	101.71	99	6	2.6	3.8	4355.6	5921.1
FreeCamDH3	5.6	4	4	148.85	139.42	142	102.53	92.92	7.5	7.9	7.1	3985.7	4047.8
FreeCamDH4	4.6	5.5	4.5	147.85	141.61	144	107.87	103.4	6	5.9	8.1	4288.4	4446.9
FreeCamDH5	4.6	5	5.5	148.85	143.5	145	95.12	99.99	7.5	7.5	6.6	3333.4	3995.8
FreeCamDH6	5.6	5.5	4.5	148.85	140.21	142.5	55.57	98.66	6	3.4	5.8	3931.9	4972.8
FreeCamDH7	4.6	6	4.5	149.85	141.14	144	106.22	97.28	6	2.6	6.5	2977	4915.9
FreeCamDH8	7.6	6	7	143.85	138.56	143	93.1	88.33	2.44E-15	2	0.5	5034.8	5776.7
FreeCamDH9	3.6	4.5	5.5	148.85	140.05	143.5	106.51	104.98	6	1.7	6.3	3824.3	4922.1
FreeCamDH10	4.6	3	5.5	150.85	144.06	143	108.06	105.93	7.5	8.3	8.4	3562.1	3928.1
FreeCamDH11	5.6	6.5	4	149.85	139.95	142	105.97	98.94	1.5	5.9	4.9	4005.9	5014.1
FreeCamDH12	4.6	5	5.5	147.85	141.02	144.5	105.55	101.57	4.5	4.8	3.3	3656.2	5098.4
FreeCamDH13	6.6	7.5	7.5	146.85	143.62	142	94.19	106.95	4.5	6	4.9	4335.4	4751.5
FreeCamDH14	4.6	5	5.5	146.85	143.12	142.5	107.38	104.17	7.5	7.8	7.1	4180.8	4765.3
FreeCamDH15	4.6	6.5	7	148.85	140.96	141.5	102.62	100.54	3	4.5	1.8	2163.3	4387.7

Supplemental Table S1.1. Continued

FreeCamDH16	4.6	5.5	5.5	147.85	140.59	143	100.37	100.41	4.5	3.7	1.5	3757.1	4918.6
FreeCamDH17	4.6	4.5	4.5	146.85	141.23	143.5	116.99	109.94	6	5.5	5.9	4550.6	5429.9
FreeCamDH18	5.6	5.5	6.5	145.85	140.5	142.5	110.01	91.37	3	1.7	0	4288.4	4455.8
FreeCamDH19	5.6	5	7	149.85	140.7	142	106.65	104.49	6	5.5	7.7	2748.3	4578.6
FreeCamDH20	6.6	4.5	5.5	143.85	140.36	142	109.71	105.21	1.5	5.7	3.2	4712	4974.4
FreeCamDH21	7.6	7	5	148.85	141.93	142.5	99.47	100.39	3	2.3	3.6	3474.6	5010.9
FreeCamDH22	4.6	5	4.5	147.85	140.62	141.5	107.82	99.32	3	3.7	2.9	4355.6	5176.6
FreeCamDH23	5.6	5.5	5	147.85	138.88	140.5	103.99	102.87	1.5	0.1	0.9	4725.5	4825.6
FreeCamDH24	6.6	5.5	6.5	147.85	140.23	140.5	102.8	101.29	4.5	1.5	2.7	3064.4	4557.7
FreeCamDH25	4.6	7	6	151.85	140.69	141.5	110.02	107.44	6	1.9	2.3	932.6	3623
FreeCamDH26	7.6	6	7	149.85	140.48	141.5	108.92	97.32	3	1.8	0.6	2270.9	4858.2
FreeCamDH27	5.6	7.5	6.5	150.85	141.05	143	114.57	105.92	3	0.3	1.6	3831.1	4782.8
FreeCamDH28	4.6	6	5	148.85	144	143.5	102.37	98.69	1.5	1.4	0.4	4200.9	5554.7
FreeCamDH29	4.6	6.5	6.5	149.85	140.02	143	108.34	101.78	3	2.1	0.8	3084.6	4760.9
FreeCamDH30	5.6	5.5	6	146.85	139.52	140.5	91.71	85.42	3	2.7	0.9	4140.4	5068.3
FreeCamDH31	5.6	6	5.5	147.85	139.97	142.5	106.46	108.67	6	5.4	4.8	4288.4	4658.6
FreeCamDH32	3.6	4.5	5.5	149.85	140.37	141.5	105.86	99.44	6	8.2	7	4288.4	4512.5
FreeCamDH33	5.6	6	5	149.85	139.82	140.5	105.44	101.23	4.5	2.3	1	4005.9	5358.3
FreeCamDH34	5.6	5	6	148.85	142.87	142.5	99.24	105.86	4.5	6.3	5.1	4248	4916.9
FreeCamDH35	5.6	7	7	149.85	142.48	143	108.07	103.89	4.5	7.1	7.2	4059.7	4892.7
FreeCamDH36	6.6	6	7.5	148.85	142.36	141	102.86	107.85	6	4.1	3	4550.6	5154.8

Supplemental Table S1.1. Continued

FreeCamDH37	4.6	5	5	150.85	140.61	140	106.97	97.03	7.5	6.9	7.7	4759.1	4716.1
FreeCamDH38	4.6	5.5	6	149.85	141.33	142	105.89	103.75	1.5	2.8	4	4106.8	4845.2
FreeCamDH39	5.7	6.5	6	148.49	139.49	140.5	107.03	97.88	1.5	2.7	2	3255.4	5201
FreeCamDH40	6.7	8	7.5	150.49	142.5	143	96.59	106.66	1.5	1	2.2	3618.6	5567.2
FreeCamDH41	4.7	6	5	151.49	140.09	140	107.87	104.89	3	6.7	3.2	2307.2	5016.2
FreeCamDH42	5.7	5	6.5	149.49	141.45	142	99.12	98.64	3	6.8	8.1	3665.7	4990.4
FreeCamDH43	4.7	4.5	6	149.49	142.92	142	109.98	102.38	7.5	7	7	3793.4	4464.7
FreeCamDH44	5.7	5.5	6	150.49	140.47	140.5	104.61	107.13	4.5	2	1.9	2744.3	4560.6
SD05W018	8.7	7.5	8	148.49	141.63	142.5	103.79	100.29	-1.33E-15	4.5	4.4	4869.4	4313.8
FreeCamDH45	4.7	7	8	151.49	142.64	144.5	104.87	99.07	-1.78E-15	3.4	3.6	3914.5	4963.5
FreeCamDH46	5.7	7	6.5	151.49	142.95	145.5	105.04	109.44	1.5	4.2	2.4	4997.2	4738.6
FreeCamDH47	4.6	5	3.5	150.49	140.4	142	112.61	96	7.5	7.8	8	3383.2	4921.8
FreeCamDH48	4.6	7.5	7.5	149.49	140.19	142.5	98.9	97.67	1.5	1.7	1.4	14	5210.6
FreeCamDH49	5.7	5.5	4.5	150.49	140.94	141	104.11	99.2	1.5	5.1	6.7	2744.3	5364.6
FreeCamDH50	6.7	6	5.5	147.49	139.56	141.5	110.29	98.59	3	2.8	2.4	3477.4	4872.2
FreeCamDH51	4.7	4.5	5	149.49	141.58	142.5	97.77	94.96	7.5	4.5	5.6	4405.4	4480.6
FreeCamDH52	5.7	5.5	4.5	147.49	140	142	101.14	98.99	1.5	0	1	4990.5	4417.2
FreeCamDH53	4.7	6	6	147.49	140.55	142.5	102.42	96.78	1.5	2.9	2.4	4230.6	4961.3
FreeCamDH54	5.7	6	4.5	149.49	140.59	141.5	107.73	100.42	3	6.1	5.8	2307.2	4199.4
FreeCamDH55	8.7	6	6	147.49	140.52	143.5	101.68	100.24	6	6.1	7.8	3067.1	4316.9
FreeCamDH56	4.7	5	5.5	145.49	140.52	143.5	112.08	111.88	7.5	7.1	7	3753.1	5213.5

Supplemental Table S1.1. Continued

FreeCamDH57	4.7	5.5	5	150.49	139.59	141.5	116.89	106.54	4.5	7.1	6.4	3793.4	4375.9
FreeCamDH58	5.7	5.5	6.5	147.49	140.88	142.5	95.21	92.72	1.5	1.6	0.4	3719.5	5495.1
FreeCamDH59	4.7	4.5	5.5	148.49	140.44	141.5	106.73	100.31	7.5	7.6	7.6	4412.1	4501.4
FreeCamDH60	3.7	7	5.5	149.49	142.61	143.5	102.53	103.89	4.5	4.8	6.9	4109.5	4440
FreeCamDH61	3.7	5	6	149.49	142.35	141	100.43	102.79	1.5	3.5	2.4	4378.5	5155.7
FreeCamDH62	3.7	5.5	6	148.49	142.32	143	106.75	94.22	-8.88E-16	0.8	0.7	3558.1	4666.2
FreeCamDH63	2.7	4.5	4	147.49	141.54	145.5	102.63	97.98	3	7.9	6.8	3793.4	5092.4
FreeCamDH64	4.7	6.5	6	147.49	141.98	142.5	106	106.48	3	1.7	2.3	4042.3	5248.5
FreeCamDH65	4.7	5.5	5.5	147.49	142.48	141.5	113.27	105.56	3	6.1	7.1	4176.8	5318.2
FreeCamDH66	4.7	6	6.5	150.49	141.88	143.5	99.07	96.34	-8.88E-16	2.4	0.8	3511	5049.2
FreeCamDH67	5.7	6	6.5	149.49	139.95	142	102.35	96.72	-8.88E-16	1.8	2.3	4270.9	4845.3
FreeCamDH68	5.7	4.5	6	149.49	141.51	141.5	101.28	96.31	1.5	1.6	1.9	3927.9	5626.1
FreeCamDH69	5.7	5	5.5	147.49	142.43	142.5	108.74	104.15	6	6.2	5.8	4291.1	4918.5
FreeCamDH70	4.7	5	5.5	147.49	142.88	141.5	94.19	90.79	6	4.5	4.3	4566.8	5456.6
FreeCamDH71	5.7	5	6	148.49	141.49	142.5	99.34	96.47	4.5	7.1	6.8	4196.9	5145.5
FreeCamDH72	6.7	5.5	7	148.49	141	142	102.72	102.62	1.5	3.1	0.9	3786.7	4801.2
FreeCamDH73	5.7	7.5	7	147.49	140.9	142	100.34	99.56	1.5	1.7	1.1	4230.6	4930.4
FreeCamDH74	5.7	4.5	4.5	147.49	144.54	141	108.01	98.84	3	1.9	3.8	4882.9	5508.1
FreeCamDH75	3.7	5	5.5	150.49	141.51	142.5	99.52	92.98	0	6.4	4.2	3860.7	4354.3
FreeCamDH76	5.0	4.5	7	150.13	140.08	140.5	99.47	96.64	6	6.7	7.4	3526.1	5061.5
FreeCamDH77	6.0	5.5	5.5	149.13	142.66	143.5	97.25	100.87	0	2.1	2.1	4326.4	5055.7

Supplemental Table S1.1. Continued

FreeCamDH78	6.0	7	4	151.13	142.53	144	107.98	102.36	8.88E-16	0.1	0	4494.5	4852
FreeCamDH79	6.0	5	5.5	149.13	141.44	141.5	104.65	97.55	1.5	5.3	7.7	3929.6	4894.6
FreeCamDH80	4.0	5	5	149.13	141.36	143.5	100.96	100.52	1.5	1.9	1.9	3344.5	5230.7
FreeCamDH81	5.0	6	4	150.13	139.39	141	105.46	101.47	3	6.6	7.9	4232.2	5028.4
FreeCamDH82	4.0	4.5	4	151.13	141.5	141	100.73	91.57	6	8.2	7.7	3983.4	4636.5
FreeCamDH83	4.0	6	6	149.13	140.35	142	99.11	95.3	1.5	1	1.5	4272.6	5460.4
FreeCamDH84	5.0	5.5	5	150.13	139.71	142	116.63	105.42	6.66E-16	7	7.2	4642.4	4614.4
FreeCamDH85	4.0	6	5.5	149.13	141.53	141.5	101.44	106.19	4.5	6.7	3.5	4124.6	5153
FreeCamDH86	6.0	5	7	149.13	138.76	142.5	100.4	98.75	6	8.3	7.6	5059.4	5101
FreeCamDH87	5.0	5.5	5.5	151.13	139.98	140.5	104.35	105.52	1.5	1.7	0.6	3687.5	5015.6
FreeCamDH88	4.0	6.5	6.5	151.13	142.01	141.5	108.15	101.1	1.5	2.3	2.8	3983.4	3807.3
FreeCamDH89	5.0	7	7.5	151.13	142.36	142	95.4	96.19	1.5	1.7	2.7	4689.5	5456.4
FreeCamDH90	4.0	3.5	6	149.13	140.64	145	103.02	101.38	1.11E-15	1.8	2.8	4023.7	5601.9
FreeCamDH91	5.0	6.5	6	149.13	142.93	142.5	101.85	94.94	1.5	2.8	0.2	4386.9	5000
FreeCamDH92	6.0	5.5	5	148.13	139.51	142	95.73	90.71	1.55E-15	0.4	2.1	3875.8	5826.2
FreeCamDH93	6.0	5.5	6.5	146.13	139.57	141.5	101.36	99.68	1.5	7.9	5.7	4871.1	5119.2
FreeCamDH94	4.0	5	5	151.13	141.51	141.5	103.13	98.54	1.11E-15	5.4	5	3566.4	4983.3
FreeCamDH95	4.0	5.5	5.5	150.13	140.09	141.5	101.75	98.58	1.5	5.2	4.4	3969.9	4725.1
FreeCamDH96	5.0	4.5	4.5	152.13	140.86	144	99.88	103.06	1.5	1.2	1.4	748.7	4781.1
FreeCamDH97	4.0	6.5	6	150.13	142.04	142.5	109.73	104.77	1.5	4.3	2.1	3734.6	4953.2
FreeCamDH98	4.0	4.5	4	151.13	144.66	141.5	97.6	99.32	1.5	1.8	0.2	3842.2	5120.9

Supplemental Table S1.1. Continued

FreeCamDH99	5.0	7.5	5	150.13	142.84	144	102.13	100.27	3	3.2	1.3	3344.5	4512.7
FreeCamDH100	4.0	6.5	6.5	150.13	141.57	141.5	106.65	101.51	1.5	2	0.8	3680.8	5723.4
FreeCamDH101	5.0	5	4	150.13	140.75	143.5	106.27	96.35	7.5	9	7.8	3546.3	4589
FreeCamDH102	6.0	6	4	146.13	139.65	143	99.52	100.06	1.5	3.3	0.3	4218.8	5315.2
FreeCamDH103	7.0	6	6	146.13	140.72	143	105.11	98.25	4.5	5.8	6.8	4427.2	5028.8
FreeCamDH104	5.0	5	5.5	150.13	138.5	140	100.26	97.53	1.5	4.5	1.5	3566.4	5329.2
FreeCamDH105	5.0	6.5	6.5	151.13	143.5	143.5	107.26	102.49	1.5	3	2.3	4494.5	4531.4
FreeCamDH106	6.0	5.5	4.5	149.13	142.73	142.5	101.39	99.89	8.88E-16	1.3	1.9	4131.3	5039
FreeCamDH107	4.0	5.5	4.5	145.13	141.92	144.5	100.16	101.05	1.5	6.2	2.5	3875.8	5539.9
FreeCamDH108	4.0	6.5	6	150.13	139.48	143	103.19	99.24	3	4.2	4.3	3822	5169.5
FreeCamDH109	4.0	5	5	149.13	139.39	144	100.32	86.32	1.5	1.8	5.9	3768.2	4973.8
FreeCamDH110	7.0	6.5	8	150.13	140.59	141	104.5	101.84	1.55E-15	0.9	0.5	4158.2	5247.4
FreeCamDH111	3.0	5	4.5	150.13	140.68	142.5	99.38	91.88	3	8	7.9	3741.3	4850.2
FreeCamDH112	4.0	4.5	5	149.13	139.77	144	109.91	101.6	1.5	4.4	7.1	4165	5020.3
FreeCamDH113	5.0	5.5	5.5	149.13	140.14	143	98.17	93.61	1.5	0.9	0.7	4548.3	5200.3
FreeCamDH114	3.5	5	5.5	147.4	141.5	142	100.25	95.48	7.5	5.6	6.3	4296.6	5652.2
FreeCamDH115	5.5	6	8	146.4	142.55	143	95.34	97.22	1.67E-15	4.2	0.2	3852.8	5291
FreeCamDH116	3.5	5	5	151.4	138.43	139.5	109.98	98	3	2.2	0.4	3126.5	4908.5
FreeCamDH117	3.5	7	7	153.4	142.25	142.5	107.38	100.24	1.5	3.1	5	3059.2	4715
FreeCamDH118	4.5	7.5	6.5	152.4	141.62	142	97.63	101.29	1.67E-15	0.6	1.2	3819.1	5013.5
FreeCamDH119	5.5	7.5	4	146.4	138.54	139.5	100.68	96.36	1.5	4.8	0.7	3146.6	4015.3

Supplemental Table S1.1. Continued

FreeCamDH120	5.5	6	5.5	150.4	142.59	143.5	104.05	104.35	3	7.6	3.2	3765.3	4703.3
FreeCamDH121	4.5	5.5	5.5	151.4	142.48	143	105.64	104.65	3	5.3	3.6	3180.3	4063.3
FreeCamDH122	4.5	5	5	149.4	140.92	143.5	102.52	99.89	1.5	7.8	2.6	3583.8	5600.1
FreeCamDH123	4.5	5	5.5	151.4	139.93	141.5	106.8	99.47	3	7.5	2.3	3301.3	4249.6
FreeCamDH124	4.5	6.5	6.5	150.4	139.55	141.5	92.5	88.71	6	5.3	6.7	3980.5	5326.1
FreeCamDH125	4.5	4	5	149.4	141.45	144	110.51	110.45	7.5	5.8	6.3	3812.4	5195.7
FreeCamDH126	4.5	7	7	149.4	141.55	139.5	96.19	95.47	6	4.7	3.2	4350.4	5633.4
FreeCamDH127	5.5	4.5	4	146.4	143.03	143	102.66	105.77	7.5	6.4	6.6	3725	3795.6
FreeCamDH128	4.5	7.5	7	148.4	140.52	141	97.6	97.43	1.5	1	1.6	3503.1	4704.6
FreeCamDH129	3.5	6	6	153.4	142.43	144	109.18	105.22	3	6	5.9	3570.3	4985.6
FreeCamDH130	6.5	6	5	147.4	138.39	143	98.73	88.16	4.5	1.3	3.4	4115	5210.7
FreeCamDH131	5.5	5.5	4	149.4	139.03	140.5	92.68	95.05	7.5	6	3.8	3180.3	4388.6
FreeCamDH132	4.5	6	5	148.4	140.17	143	97.97	99.5	6	3.5	3.3	4047.8	5551.4
FreeCamDH133	4.5	5.5	5.5	150.4	141.31	142	109.67	96.57	6	4.1	6.1	3482.9	5128.4
FreeCamDH134	5.5	5	5	146.4	140.18	142	100.5	100.89	7.5	6.2	3	3819.1	4774.3
FreeCamDH135	4.5	7	6.5	151.4	140.87	143.5	100.96	98.6	3	2.8	2.1	3731.7	4639.4
FreeCamDH136	6.5	7.5	7.5	151.4	141.14	142	102.18	103.15	3	3.8	2.4	3462.7	5095.5
FreeCamDH137	4.5	6	4.5	150.4	139.79	142	87.62	80.29	1.5	1.2	4.3	3603.9	5712.8
FreeCamDH138	6.5	7	5.5	149.4	141.06	145	102.07	96.08	6	7.5	7.8	3953.6	4515.4
FreeCamDH139	3.5	5	5.5	151.4	139.14	140.5	98.23	94.6	4.5	1.7	2.9	2931.4	4592.4
FreeCamDH140	6.5	7	7.5	149.4	142.58	142.5	97.21	96.38	1.5	3.9	0.2	4572.3	5111.6

Supplemental Table S1.1. Continued

FreeCamDH141	4.5	5	4	149.4	140.36	141	108.21	96.48	1.5	6.6	3.1	3940.2	4960.6
FreeCamDH142	5.5	6.5	7	150.4	140.96	143.5	105.26	102.25	1.5	4.3	3.2	3745.2	4679.5
FreeCamDH143	4.5	5.5	5.5	149.4	140.45	143	102.49	101.83	3	6	3.1	3973.8	4425.6
FreeCamDH144	4.5	5.5	4.5	145.4	141.59	142.5	99.2	87.33	5.22E-15	0.4	0.2	4350.4	5036.4
FreeCamDH145	4.5	5	6	146.4	140.41	141.5	106.62	94.97	3	5.9	3.7	3657.7	5668.2
FreeCamDH146	3.5	4.5	6	151.4	143.57	141.5	103.1	101.06	7.5	6.9	7.2	3281.1	4484.5
FreeCamDH147	4.5	6	6	149.4	141.97	142	102.81	93.82	1.5	4.4	1.7	3799	4992.2
FreeCamDH148	4.5	3.5	5.5	151.4	142.5	142.5	113.55	108.01	6	6.5	7.7	3267.7	4318.1
FreeCamDH149	4.5	4.5	4.5	149.4	142.66	142.5	100.26	97.9	7.5	8.3	9	3254.2	3519.3
FreeCamDH150	5.5	5.5	5.5	149.4	142.11	142	103.22	99.32	3	5.7	5.3	3926.7	4077.7
FreeCamDH151	3.5	5.5	5	150.4	143.05	145	109.1	108.71	3.33E-15	5.3	4.5	3657.7	4525.7
FreeCamDH152	5.0	5.5	6	149.13	140.44	142.5	97.28	98.76	1.5	4.6	0.6	3456.6	5230.6
FreeCamDH153	6.0	6	6	144.13	140.43	142.5	106.81	105.26	7.5	7.5	7.2	4001.3	5364.8
FreeCamDH154	6.0	6	5.5	146.13	140.24	141	107.57	99.55	1.5	4.9	4.2	3947.5	4250.5
FreeCamDH155	6.0	6	5	148.13	141.91	142.5	97.51	96.7	4.5	6.8	5.4	4021.5	5024.4
FreeCamDH156	5.0	5.5	6	148.13	139.17	142	97.14	101.86	4.5	3.1	3.3	3611.2	4527.7
FreeCamDH157	5.0	5	7	149.13	141.44	142.5	99.71	97.8	1.5	6	4.2	3416.2	5273.2
FreeCamDH158	6.0	6.5	4.5	145.13	139.36	140	109.24	100.23	1.5	3.7	2.3	3880.2	4555.5
FreeCamDH159	4.0	5	3.5	150.13	142.31	144.5	101.3	99.77	3	7.9	5.5	4606.5	5008.6
FreeCamDH160	7.0	7.5	7	149.13	141.9	141.5	100.31	100.47	3.89E-15	1.3	0	4882.3	5404.1
FreeCamDH161	4.0	5	5	150.13	141.67	143	105.85	98.77	1.5	2.6	3.6	4129.1	5268.5

Supplemental Table S1.1. Continued

FreeCamDH162	6.0	6.5	6.5	148.13	140.98	142.5	116.99	102.64	1.5	3.9	4.9	4229.9	5144.5
FreeCamDH163	4.0	6	4.5	150.13	139.06	142.5	108	95.22	6	5.6	6.9	3476.7	5573.3
FreeCamDH164	6.0	5.5	5.5	149.13	140.07	142.5	99.13	101.2	4.5	5.2	4.7	4714.1	5206.2
FreeCamDH165	5.0	6.5	6	149.13	142.75	143.5	103.82	100.75	3	1.4	0.1	4431.7	6216.1
FreeCamDH166	4.0	5	4.5	149.13	144.07	142.5	102.69	103.55	1.5	5.4	4	4357.7	4467
FreeCamDH167	5.0	5	6.5	151.13	139.08	141.5	96.81	96.74	1.5	6.6	7.4	3362.4	5208.8
FreeCamDH168	5.0	5	5.5	147.13	142.83	143.5	100.63	96.28	3.66E-15	1.7	1.6	4055.1	5284.4
FreeCamDH169	4.0	5	6	151.13	140.1	143	109.18	108.93	1.5	5.4	4.2	3981.1	4881.4
FreeCamDH170	5.0	5.5	5.5	150.13	139.98	141	94.86	95.59	3.55E-15	4.9	1.7	4014.7	5056.2
FreeCamDH171	6.0	5.5	3.5	149.13	139.04	139	109.64	104.38	4.5	6.1	5.3	5023.5	5236.3
FreeCamDH172	5.0	5.5	7	146.13	140.1	142	102.08	91.06	1.5	5.5	0.6	4431.7	5509.4
FreeCamDH173	2.0	3.5	5	144.13	138.18	140.5	103.99	91.42	3.77E-15	1.4	0.2	2185.5	3537.2
FreeCamDH174	8.0	8	8	149.13	143.11	143	110.77	99.63	3.89E-15	1.2	0.3	4599.8	4547.8
Camelot	3.6	4	3.5	148.6	142.99	140.5	105.37	105.17	2.1	4.5	-0.2	4154.7	5265
Freeman	6.6	6	6.5	147.8	138.52	140	109.2	103.11	0.9	6.4	6	4407.5	4950.9
TAM107	5.0	5.5	5.5	144.13	138.86	140	106.29	99.31	1.5	0.3	-0.1	3860.1	4775.3
NI15713	7.0	6	5.5	145.13	140.11	142.5	108.2	98.26	1.5	7	6.6	4209.8	4714.4
Pete	6.0	3	2.5	149.13	138.38	137.5	101.52	90.89	3	1.1	0.1	5164.7	3854.3

SUMMARY OF ANALYSIS OF VARIANCE (ANOVA) USING 180 GENOTYPES INCLUDING DHS DERIVED FROM FREEMAN AND CAMELOT AND CHECKS GROWN AT THREE DIFFERENT ENVIRONMENTS

TRAITS	AE	AE	AE	AD	AD	AD	PH	PH	LODG	LODG	LODG	GYLD	GYLD
CV%	19.9	14.5	17	1.17	0.8	1.04	6.76	4	69.6	32.8	49.9	0.18	7.84

Supplemental Table S1.1. Continued

ERROR D.F.	4	179	179	4	109	179	109	109	4	109	109	4	109
MEAN	5.08	5.66	5.63	149	141	142.2	103.2	99.6	3.14	4.28	3.79	3857	4914.9
SED	1.0147	0.824	0.963	1.757	1.131	1.492	6.981	3.989	2.186	1.407	1.8941	6.9554	385.481
MAX	8.7	8	8	153.4	144.66	145.5	116.99	111.88	7.5	9.1	9	5164.76	6216.14
MIN	2.0	3	2.5	143.85	138.18	137.5	55.57	80.29	0	0	0	14.0219	3519.31
σ^2 Genotypic	0.5539^{NS}	0.592^{**}	0.664^{**}	1.555^{NS}	1.319^{**}	0.5435^{*}	14.29^{*}	17.77^{**}	1.824^{NS}	4.593^{**}	5.109^{**}	48.2243*	150898^{**}
σ^2Residual	1.02	0.68	0.928	3.0889	1.28	1.28	48.742	15.917	4.7827	1.98	3.588	48.3777	148596
σ^2Phenotypic	1.02	0.932	1.1285	3.0889	1.959	1.1835	38.662	25.729	4.7827	5.583	6.903	48.3777	225197
R^2	0.35	0.63	0.58	0.33	0.67	0.45	0.36	0.69	0.28	0.82	0.74	0.5	0.67

Abbreviations; μ, mean; SED, the standard error of difference; MAX, maximum; MIN, minimum; σ^2 Genotypic, genotypic variance; σ^2Phenotypic, phenotypic variance; σ^2Residual, error variance; CV, coefficient of variation; R^2, repeatability estimates of traits measured.
Trait abbreviations; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
NS, not significant at the 0.05 probability level.

Supplemental Table S1.2. Over environments analysis combining 180 BLUEs of 2021L and 2021M including checks and parental lines conducted as two replications in 2021 at Lincoln and Mead respectively.

Combined analyses using BLUEs of 2021L and 2021M populations conducted as two replications in 2021				
TRAITS	**AE**	**AD**	**PH**	**LODG**
ALPHA LEVEL	0.05	0.05	0.05	0.05
CV%	15.87	0.93	5.61	41.34
D.F.	358	358	358	358
μ	5.65	141.65	101.43	4.03
SED	0.8244	0.9634	1.1313	1.4926
LSD	1.247	1.754	2.242	2.320
MAX	8	144.25	113.47	8.65
MIN	2.75	137.94	77.12	0.05
$\boldsymbol{\sigma^2_G}$	0.511 **	0.726 **	14.681 **	4.51 **
$\boldsymbol{\sigma^2_{GXE}}$	0.117 *	0.215 *	1.949 NS	0.108 NS
$\boldsymbol{\sigma^2_{RES}}$	0.804	1.754	32.329	2.784
$\boldsymbol{\sigma^2_P}$	1.315	2.48	47	2.771
$\boldsymbol{R^2}$	0.66	0.57	0.61	0.85

Trait abbreviations; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging.
Abbreviations; CV, coefficient of variation; D.F, degree of freedom for residual; μ, grand mean; SED, the standard error of difference; LSD, the least significant difference; MAX, maximum; MIN, minimum; σ^2_G, genotypic variance; σ^2GxE, variance due to G x E interactions; σ^2Res, error variance; σ^2_P, phenotypic variance; R^2, the broad sense repeatability for four traits measured.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
NS, not significant at the 0.05 probability level.

Supplemental Table S2. Loading values shows contributions of 174 DHs to three extracted PCAs for AE, AD, PH, LODG and GYLD.

Name	**PCA_1**			**PCA_2**			**PCA_3**		
Location	2020L	2021L	2021M	2020L	2021L	2021M	2020L	2021L	2021M
FreeCamDH1	1.88	-1.41	-1.07	-0.1	-0.1	0.57	0	0.4	-1.8
FreeCamDH2	1.53	-1.34	-0.64	-0.47	0.7	1.33	-0.6	1	-1.6
FreeCamDH3	1.53	-1.62	-0.33	-0.96	-2.4	-1.7	-0.7	0.3	-0.9
FreeCamDH4	1.77	-1.58	-0.27	-1.11	-0.8	-1.6	-0.4	0.4	-1.3
FreeCamDH5	1.67	-1.08	-0.29	-1.66	-1.6	-0.6	-0.2	0.3	-1
FreeCamDH6	1.62	-0.97	-0.2	-0.52	-0.1	-0.9	-0.4	1.1	-1.1
FreeCamDH7	1.88	-1.54	0	-1.28	0.4	-1.1	0.15	1	-1.2
FreeCamDH8	0.88	-1.74	-0.14	2.66	0.59	2.27	-0.2	1.1	-0.8
FreeCamDH9	2.11	-1.26	-0.42	-1.81	-0.2	-0.4	0	1.3	-1.4
FreeCamDH10	2.04	-0.69	-0.83	-1.66	-3.1	-1.1	-0.3	0.5	-1.4
FreeCamDH11	2.1	-2.07	-0.09	0.78	-0.2	-0.9	0.42	0.2	-0.9
FreeCamDH12	1.77	-1.44	0.01	-0.74	-0.8	0.41	0.1	0.7	-0.8
FreeCamDH13	1.21	-1.6	-1.14	0.60	0.33	1.2	-0.5	0.2	-1.4
FreeCamDH14	1.49	-1.33	-0.66	-1.55	-1.7	-0.7	-0.6	0.2	-1.5
FreeCamDH15	1.78	-1.77	-0.86	-0.48	0.16	1.75	0.99	0.5	-0.6
FreeCamDH16	1.79	-1.5	-0.12	-0.73	-0.2	0.93	0.06	0.9	-0.5
FreeCamDH17	1.66	-1.48	-0.11	-1.07	-1.3	-0.9	-0.5	0.6	-1.4
FreeCamDH18	1.39	-1.5	-0.33	0.41	0.35	1.93	0	1.2	-0.2
FreeCamDH19	1.58	-1.55	-1.2	-0.67	-1	0.05	0.07	0.6	-1.8
FreeCamDH20	0.98	-1.53	-0.45	1.55	-1.4	0.45	-0.2	0.6	-0.9

Supplemental Table S2. Continued

FreeCamDH20	0.98	-1.53	-0.45	1.55	-1.4	0.45	-0.2	0.6	-0.9
FreeCamDH21	1.23	-1.56	-0.2	1.56	1.11	0.02	0	0.9	-0.8
FreeCamDH37	2.24	-1.67	-0.89	-1.52	-1.4	-1.1	-0.7	0.3	-1.5
FreeCamDH38	2.37	-1.39	-0.64	0.16	0.02	0.52	0.54	1	-1
FreeCamDH39	1.69	-1.95	-0.61	0.84	0.7	1.16	0.63	0.8	-0.8
FreeCamDH40	1.82	-1.6	-0.65	1.49	2.12	2.07	0.39	1	-1.2
FreeCamDH41	2.18	-2.01	-0.64	-0.36	-0.7	0.16	0.98	0.2	-0.9
FreeCamDH42	1.82	-1.42	-0.95	0.43	-1.4	-0.3	0.23	0.4	-1.9
FreeCamDH43	1.8	-1.21	-0.89	-1.49	-1.8	-0.3	-0.4	0.4	-1.4
FreeCamDH44	1.73	-1.45	-0.83	-0.11	0.26	1.12	0.34	1.1	-0.6
FreeCamDH45	2.65	-1.59	-0.63	0.68	0.79	1.9	0.91	0.7	-1.3
FreeCamDH46	2.48	-1.58	-0.17	1.00	0.55	1.26	0.05	0.6	-0.7
FreeCamDH47	1.89	-1.84	-0.15	-1.55	-1.7	-2.2	-0.2	0.1	-1.4
FreeCamDH48	1.3	-1.92	-0.62	0.46	1.62	2.27	1.93	0.9	-0.9
FreeCamDH49	2.19	-1.59	-0.45	0.12	-0.6	-1.1	1.06	0.6	-1.5
FreeCamDH50	2.24	-1.85	-0.41	-1.46	0.36	0.68	0.74	0.9	-0.7
FreeCamDH51	1.65	-1.1	-0.36	-0.79	-1.1	-0.6	-0.8	0.9	-1
FreeCamDH52	2.08	-1.34	-0.06	0.41	0.91	0.4	0.09	1.6	-0.1
FreeCamDH53	1.95	-1.6	-0.34	0.32	0.31	0.99	0.39	0.9	-0.7
FreeCamDH54	1.85	-1.88	-0.52	-0.34	-0.6	-1	0.92	0.3	-0.9
FreeCamDH55	1.45	-1.82	-0.69	-1.12	-0.6	-0.6	0.01	0.3	-1.5

Supplemental Table S2. Continued

FreeCamDH56	0.88	-1.77	-0.51	-0.82	-1.5	-0.6	-0.7	0.3	-1.6
FreeCamDH57	2.16	-2.1	-0.74	-0.62	-1.2	-0.8	0.1	0.1	-1.2
FreeCamDH58	1.61	-1.24	-0.19	0.90	0.37	1.95	0.42	1.3	-0.7
FreeCamDH59	1.74	-1.62	-0.85	-1.41	-2	-0.8	-0.7	0.3	-1.5
FreeCamDH60	2.31	-1.66	-0.53	-1.21	0.38	-0.6	0.11	0.5	-1.3
FreeCamDH61	2.56	-1.06	-0.63	-0.31	-0.5	1.03	0.56	1	-0.9
FreeCamDH62	2.36	-1.11	-0.16	0.04	0.6	1.45	1.13	1.4	-0.3
FreeCamDH63	2.29	-1.41	0.37	-1.43	-2.1	-1.5	0.61	0.3	-1.2
FreeCamDH64	1.82	-1.46	-0.41	-0.13	0.97	1.06	0.19	1.1	-0.9
FreeCamDH65	1.84	-1.51	-0.74	-0.11	-0.9	-0.6	0.13	0.4	-1.7
FreeCamDH66	2.42	-1.31	-0.17	0.65	0.45	1.78	1.04	1.1	-0.5
FreeCamDH67	2.13	-1.62	-0.56	1.38	0.64	1.33	0.55	1.1	-0.8
FreeCamDH68	1.97	-0.96	-0.35	0.90	-0.2	1.22	0.4	1.4	-0.9
FreeCamDH69	1.4	-1.35	-0.54	-0.34	-1.2	-0.3	-0.6	0.5	-1.3
FreeCamDH70	1.7	-0.97	-0.34	-0.95	-0.8	0.18	-0.5	0.9	-1.2
FreeCamDH71	1.65	-1.44	-0.6	0.07	-1.5	-0.2	-0.2	0.3	-1.6
FreeCamDH72	1.53	-1.42	-0.68	1.53	0	2.06	0.26	1	-0.6
FreeCamDH73	1.7	-1.82	-0.63	0.96	1.61	2.01	0.22	0.9	-0.7
FreeCamDH74	1.7	-0.58	-0.22	0.59	-0.3	-0.2	-0.3	1.4	-1
FreeCamDH75	2.74	-1.39	-0.39	0.05	-1.3	0.08	1.07	0.5	-0.7
FreeCamDH76	1.87	-1.51	-1.24	-0.9	-1.7	0.2	-0.1	0.5	-1.9

Supplemental Table S2. Continued

FreeCamDH77	2	-1.01	-0.06	1.58	0.21	0.77	0.46	1.2	-0.6
FreeCamDH78	2.35	-1.43	0.50	1.58	1.75	0.46	0.46	1.3	0.08
FreeCamDH79	1.83	-1.4	-0.75	1.10	-1	-0.8	0.34	0.6	-1.7
FreeCamDH80	2.24	-1.12	0.11	-0.23	0	0.53	0.9	1.3	-0.6
FreeCamDH81	2.2	-2.08	-0.49	0.05	-0.7	-1.8	0.14	0.2	-1.5
FreeCamDH82	2.37	-1.4	-0.42	-1.49	-2.1	-1.8	-0.1	0.2	-1.3
FreeCamDH83	2.4	-1.46	-0.25	-0.13	0.87	1.32	0.54	1.3	-0.8
FreeCamDH84	2.47	-2.07	-0.66	0.97	-1.1	-1	0.54	0.1	-1.4
FreeCamDH85	2.17	-1.69	-0.53	-1.02	-0.8	0.39	0.04	0.2	-1
FreeCamDH86	1.72	-1.97	-0.95	-0.08	-1.8	0.13	-0.9	0	-1.9
FreeCamDH87	2.37	-1.51	-0.52	0.42	0.35	1.23	0.66	1.2	-0.4
FreeCamDH88	2.68	-1.53	-0.91	-0.18	0.8	1.08	0.71	1	-0.5
FreeCamDH89	2.54	-1.39	-0.73	0.53	1.28	1.92	0.27	1	-1.3
FreeCamDH90	2.46	-0.89	0.08	0.27	-0.9	0.93	0.91	1.5	-1
FreeCamDH91	2.16	-1.34	-0.16	0.51	0.64	1.64	0.33	0.9	-0.3
FreeCamDH92	1.76	-1.39	0.07	1.54	0.73	0.55	0.61	1.4	-0.9
FreeCamDH93	1.5	-1.96	-0.86	1.23	-1.4	0.38	-0.1	0	-1.5
FreeCamDH94	2.71	-1.37	-0.44	0.20	-1	-0.3	1.15	0.6	-1.1
FreeCamDH95	2.51	-1.7	-0.57	-0.17	-0.6	0.08	0.69	0.6	-1
FreeCamDH96	2.03	-1.02	0.24	0.08	-0.1	0.3	1.84	1.5	-0.2
FreeCamDH97	2.47	-1.68	-0.42	-0.2	0.21	1.09	0.78	0.6	-0.7

Supplemental Table S2. Continued

FreeCamDH98	2.65	-0.41	0.15	-0.19	-0.3	0.4	0.77	1.5	-0.1
FreeCamDH99	2.05	-1.64	0.11	-0.04	1.16	0.62	0.49	0.7	-0.2
FreeCamDH100	2.46	-1.56	-0.45	-0.2	0.89	1.88	0.8	1	-0.9
FreeCamDH101	1.78	-1.78	-0.08	-1.33	-2.1	-1.9	-0.4	0	-1.2
FreeCamDH102	1.39	-1.73	0.41	1.16	0.2	0.37	0.14	0.8	-0.2
FreeCamDH103	0.96	-1.81	-0.56	0.94	-0.5	-0.2	-0.6	0.4	-1.6
FreeCamDH104	2.19	-1.76	-0.5	0.41	-0.7	1.01	0.68	0.7	-0.7
FreeCamDH105	2.51	-1.32	-0.44	0.51	0.58	1.29	0.35	0.9	-0.6
FreeCamDH106	1.96	-1	0.05	1.56	0.44	0.2	0.54	1.4	-0.4
FreeCamDH107	1.68	-1.45	0.40	-0.13	-0.9	0.06	0.57	0.4	-0.7
FreeCamDH108	2.39	-2	-0.38	-0.62	0.26	0.46	0.47	0.5	-1.2
FreeCamDH109	2.31	-1.43	0.05	-0.18	0.01	-0.6	0.74	1.3	-1.1
FreeCamDH110	1.88	-1.62	-0.98	2.19	1.22	2.87	0.39	1.2	-0.9
FreeCamDH111	2.63	-1.63	-0.28	-1.27	-1.8	-1.5	0.66	0.1	-1.5
FreeCamDH112	2.38	-1.54	-0.21	-0.14	-1	-1	0.58	0.8	-1.4
FreeCamDH113	2.19	-1.36	0.06	0.53	0.58	1.19	0.27	1.4	-0.4
FreeCamDH114	1.87	-1.35	-0.42	-2.24	-1.1	-0.3	-0.5	0.6	-1.7
FreeCamDH115	1.63	-1.27	-0.57	1.17	0	2.94	0.66	0.8	-0.8
FreeCamDH116	2.63	-1.75	-0.46	-1.1	0	0.97	0.88	1.1	-0.3
FreeCamDH117	3.05	-1.65	-0.86	-0.68	0.88	0.84	1.24	0.7	-1.3
FreeCamDH118	2.86	-1.6	-0.51	0.47	1.93	1.68	1.03	1.1	-0.7

Supplemental Table S2. Continued

FreeCamDH119	1.41	-2.43	-0.35	0.65	0.73	0.14	0.66	0.3	0.12
FreeCamDH120	2.07	-1.61	-0.24	0.25	-1	0.41	0.27	0.1	-0.7
FreeCamDH121	2.39	-1.36	-0.46	-0.45	-0.7	0.22	0.69	0.6	-0.6
FreeCamDH122	2.23	-1.62	0.13	0.04	-1.7	0.36	0.75	0.2	-0.8
FreeCamDH123	2.41	-1.82	-0.52	-0.44	-1.6	0.64	0.64	0.2	-0.4
FreeCamDH124	2.16	-1.92	-0.75	-1.23	0	0.1	-0.2	0.4	-1.8
FreeCamDH125	1.86	-1.24	-0.24	-1.68	-1.8	-0.7	-0.4	0.7	-1.4
FreeCamDH126	2.05	-1.73	-1.01	-1.18	0.41	1.5	-0.3	0.5	-1.4
FreeCamDH127	1.1	-1.06	-0.34	-1.02	-1.6	-1.6	-0.6	0.6	-0.8
FreeCamDH128	2.05	-1.81	-0.84	0.04	1.82	1.85	0.75	1	-0.7
FreeCamDH129	3.03	-1.6	-0.43	-1.07	-0.6	0	0.77	0.4	-1.4
FreeCamDH130	1.28	-1.8	0.08	0.51	0.8	0.09	-0.4	1.2	-0.8
FreeCamDH131	1.5	-1.82	-0.32	-1.11	-0.8	-0.7	-0.3	0.4	-0.5
FreeCamDH132	1.84	-1.65	0.00	-1.2	0.14	0.16	-0.2	0.8	-1
FreeCamDH133	2.07	-1.53	-0.51	-1.29	-0.3	-0.3	0	0.8	-1.4
FreeCamDH134	1.12	-1.6	-0.29	-1.01	-1.2	0.17	-0.7	0.5	-0.7
FreeCamDH135	2.48	-1.78	-0.36	-0.39	0.98	1.36	0.48	0.8	-0.6
FreeCamDH136	1.92	-1.96	-0.86	0.84	1	1.97	0.25	0.5	-1.1
FreeCamDH137	2.4	-1.42	0.17	0.03	0.81	-0.4	0.77	1.3	-1.1
FreeCamDH138	1.47	-2.08	-0.23	0.04	-0.3	-0.9	-0.5	0	-1.4
FreeCamDH139	2.5	-1.45	-0.6	-1.56	0.04	0.51	0.68	1.3	-0.7

Supplemental Table S2. Continued

FreeCamDH140	1.88	-1.53	-0.54	1.42	0.64	2.61	0.03	0.6	-0.6
FreeCamDH141	2.29	-1.7	-0.11	0.08	-1.3	-0.4	0.61	0.4	-0.6
FreeCamDH142	2.16	-1.79	-0.6	0.68	0.22	1.36	0.55	0.6	-0.9
FreeCamDH143	2.19	-1.7	-0.33	-0.35	-0.9	0.41	0.32	0.4	-0.6
FreeCamDH144	1.81	-1.1	0.32	0.60	0.72	0.69	0.61	1.5	-0.1
FreeCamDH145	1.65	-1.63	-0.45	-0.35	-1.1	0.7	0.35	0.5	-1.3
FreeCamDH146	2.35	-1	-0.96	-2.39	-1.8	-0.4	0	0.5	-1.5
FreeCamDH147	2.27	-1.48	-0.33	0.06	-0.1	1.21	0.67	0.7	-0.6
FreeCamDH148	2.2	-1.03	-0.82	-1.32	-2.3	-0.9	0.1	0.7	-1.4
FreeCamDH149	1.77	-1.21	-0.66	-1.74	-2.2	-2	-0.2	0.2	-1.2
FreeCamDH150	1.93	-1.42	-0.67	0.27	-0.8	-0.2	0.17	0.5	-0.9
FreeCamDH151	2.76	-1.31	-0.04	-0.15	-0.7	-0.3	1.2	0.6	-0.8
FreeCamDH152	2	-1.55	-0.19	0.41	-0.4	1.55	0.69	0.7	-0.5
FreeCamDH153	0.62	-2	-0.7	-0.59	-1	-0.3	-0.9	0	-1.8
FreeCamDH154	1.34	-1.86	-0.73	1.13	-0.2	0.09	0.24	0.5	-0.8
FreeCamDH155	1.48	-1.59	-0.27	0.24	-0.8	-0.5	-0.2	0.2	-1.2
FreeCamDH156	1.66	-1.64	-0.62	-0.43	0	0.69	0.04	0.9	-0.8
FreeCamDH157	2	-1.39	-0.68	0.40	-1.2	1.14	0.71	0.5	-1.4
FreeCamDH158	1.17	-2.06	-0.47	1.13	0.41	0.05	0.24	0.6	-0.4
FreeCamDH159	2.52	-1.39	0.38	-0.54	-1.7	-1.5	0.16	0.2	-0.9
FreeCamDH160	1.84	-1.63	-0.57	2.28	1.72	2.36	0.08	1	-0.7

Supplemental Table S2. Continued

FreeCamDH161	2.54	-1.19	-0.05	-0.15	-0.2	0.04	0.63	1.2	-0.9
FreeCamDH162	1.72	-1.91	-0.68	1.14	0.34	0.6	0.19	0.6	-1.4
FreeCamDH163	2.12	-2.1	-0.13	-1.54	-0.4	-1.2	0.05	0.3	-1.6
FreeCamDH164	1.76	-1.66	-0.38	0.31	-0.6	0.03	-0.5	0.6	-1.2
FreeCamDH165	2.07	-1.28	0.13	0.08	1.05	1.8	0.03	1.2	-0.8
FreeCamDH166	2.41	-0.94	-0.23	-0.12	-1	-0.4	0.51	0.7	-0.6
FreeCamDH167	2.32	-1.76	-0.92	0.38	-1.3	-0.1	0.79	0.4	-1.9
FreeCamDH168	1.88	-0.88	0.06	0.93	0.01	0.94	0.67	1.4	-0.6
FreeCamDH169	2.68	-1.68	-0.55	-0.18	-1	0.46	0.71	0.6	-1.1
FreeCamDH170	2.36	-1.61	-0.37	0.90	-0.5	0.91	0.78	0.6	-0.6
FreeCamDH171	1.81	-2.04	-0.51	0.34	-0.9	-1.3	-0.6	0.3	-1.1
FreeCamDH172	1.68	-1.72	-0.39	0.55	-0.7	2.22	0.22	0.5	-0.8
FreeCamDH173	1.84	-1.27	-0.43	-1.14	-0.8	0.86	1.81	1.5	0.29
FreeCamDH174	1.53	-1.69	-0.73	2.88	2.06	2.83	0.02	0.9	-0.5

Abbreviations; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield; PC, principal component.

Supplemental Table S3. K- means clustering results based on GAP statistics subgrouping three experiments into 4 clusters.

EXPERIMENTS					
2020L		2021L		2021M	
ENTRY (FxC20LIM)	CLUSTER (k)	ENTRY (FxC21LIM)	CLUSTER (k)	ENTRY (FxC21MD)	CLUSTER (k)
FreeCamDH1	1	FreeCamDH1	2	FreeCamDH1	4
FreeCamDH2	1	FreeCamDH2	2	FreeCamDH2	3
FreeCamDH3	1	FreeCamDH3	2	FreeCamDH3	4
FreeCamDH4	1	FreeCamDH4	2	FreeCamDH4	4
FreeCamDH5	1	FreeCamDH5	2	FreeCamDH5	4
FreeCamDH6	1	FreeCamDH6	2	FreeCamDH6	4
FreeCamDH7	1	FreeCamDH7	2	FreeCamDH7	4
FreeCamDH8	3	FreeCamDH8	2	FreeCamDH8	3
FreeCamDH9	1	FreeCamDH9	2	FreeCamDH9	4
FreeCamDH10	1	FreeCamDH10	2	FreeCamDH10	4
FreeCamDH11	1	FreeCamDH11	2	FreeCamDH11	4
FreeCamDH12	1	FreeCamDH12	2	FreeCamDH12	3
FreeCamDH13	1	FreeCamDH13	2	FreeCamDH13	3
FreeCamDH14	1	FreeCamDH14	2	FreeCamDH14	4
FreeCamDH15	1	FreeCamDH15	2	FreeCamDH15	3
FreeCamDH16	1	FreeCamDH16	2	FreeCamDH16	3
FreeCamDH17	1	FreeCamDH17	2	FreeCamDH17	4

Supplemental Table S3. Continued

FreeCamDH18	1	FreeCamDH18	2	FreeCamDH18	3
FreeCamDH19	1	FreeCamDH19	2	FreeCamDH19	4
FreeCamDH20	3	FreeCamDH20	2	FreeCamDH20	3
FreeCamDH21	1	FreeCamDH21	2	FreeCamDH21	4
FreeCamDH22	1	FreeCamDH22	2	FreeCamDH22	3
FreeCamDH23	1	FreeCamDH23	2	FreeCamDH23	3
FreeCamDH24	1	FreeCamDH24	2	FreeCamDH24	3
FreeCamDH25	1	FreeCamDH25	2	FreeCamDH25	3
FreeCamDH26	1	FreeCamDH26	2	FreeCamDH26	3
FreeCamDH27	1	FreeCamDH27	2	FreeCamDH27	3
FreeCamDH28	1	FreeCamDH28	2	FreeCamDH28	3
FreeCamDH29	1	FreeCamDH29	2	FreeCamDH29	3
FreeCamDH30	1	FreeCamDH30	2	FreeCamDH30	3
FreeCamDH31	1	FreeCamDH31	2	FreeCamDH31	4
FreeCamDH32	1	FreeCamDH32	2	FreeCamDH32	4
FreeCamDH33	1	FreeCamDH33	2	FreeCamDH33	3
FreeCamDH34	1	FreeCamDH34	2	FreeCamDH34	4
FreeCamDH35	1	FreeCamDH35	2	FreeCamDH35	4
FreeCamDH36	1	FreeCamDH36	2	FreeCamDH36	3
FreeCamDH37	1	FreeCamDH37	2	FreeCamDH37	4
FreeCamDH38	1	FreeCamDH38	2	FreeCamDH38	3
FreeCamDH39	1	FreeCamDH39	2	FreeCamDH39	3

Supplemental Table S3. Continued

FreeCamDH40	1	FreeCamDH40	2	FreeCamDH40	3
FreeCamDH41	1	FreeCamDH41	2	FreeCamDH41	3
FreeCamDH42	1	FreeCamDH42	2	FreeCamDH42	4
FreeCamDH43	1	FreeCamDH43	2	FreeCamDH43	4
FreeCamDH44	1	FreeCamDH44	2	FreeCamDH44	3
FreeCamDH45	1	FreeCamDH45	2	FreeCamDH45	3
FreeCamDH46	1	FreeCamDH46	2	FreeCamDH46	3
FreeCamDH47	1	FreeCamDH47	2	FreeCamDH47	4
FreeCamDH48	1	FreeCamDH48	2	FreeCamDH48	3
FreeCamDH49	1	FreeCamDH49	2	FreeCamDH49	4
FreeCamDH50	1	FreeCamDH50	2	FreeCamDH50	3
FreeCamDH51	1	FreeCamDH51	2	FreeCamDH51	4
FreeCamDH52	1	FreeCamDH52	2	FreeCamDH52	3
FreeCamDH53	1	FreeCamDH53	2	FreeCamDH53	3
FreeCamDH54	1	FreeCamDH54	2	FreeCamDH54	4
FreeCamDH55	1	FreeCamDH55	2	FreeCamDH55	4
FreeCamDH56	1	FreeCamDH56	2	FreeCamDH56	4
FreeCamDH57	1	FreeCamDH57	2	FreeCamDH57	4
FreeCamDH58	1	FreeCamDH58	2	FreeCamDH58	3
FreeCamDH59	1	FreeCamDH59	2	FreeCamDH59	4
FreeCamDH60	1	FreeCamDH60	2	FreeCamDH60	4
FreeCamDH61	1	FreeCamDH61	2	FreeCamDH61	3

Supplemental Table S3. Continued

FreeCamDH62	1	FreeCamDH62	2	FreeCamDH62	3
FreeCamDH63	1	FreeCamDH63	2	FreeCamDH63	4
FreeCamDH64	1	FreeCamDH64	2	FreeCamDH64	3
FreeCamDH65	1	FreeCamDH65	2	FreeCamDH65	4
FreeCamDH66	1	FreeCamDH66	2	FreeCamDH66	3
FreeCamDH67	1	FreeCamDH67	2	FreeCamDH67	3
FreeCamDH68	1	FreeCamDH68	2	FreeCamDH68	3
FreeCamDH69	1	FreeCamDH69	2	FreeCamDH69	4
FreeCamDH70	1	FreeCamDH70	2	FreeCamDH70	4
FreeCamDH71	1	FreeCamDH71	2	FreeCamDH71	4
FreeCamDH72	1	FreeCamDH72	2	FreeCamDH72	3
FreeCamDH73	1	FreeCamDH73	2	FreeCamDH73	3
FreeCamDH74	1	FreeCamDH74	2	FreeCamDH74	4
FreeCamDH75	1	FreeCamDH75	2	FreeCamDH75	4
FreeCamDH76	1	FreeCamDH76	2	FreeCamDH76	4
FreeCamDH77	1	FreeCamDH77	2	FreeCamDH77	3
FreeCamDH78	1	FreeCamDH78	2	FreeCamDH78	3
FreeCamDH79	1	FreeCamDH79	2	FreeCamDH79	4
FreeCamDH80	1	FreeCamDH80	2	FreeCamDH80	3
FreeCamDH81	1	FreeCamDH81	2	FreeCamDH81	4
FreeCamDH82	1	FreeCamDH82	2	FreeCamDH82	4
FreeCamDH83	1	FreeCamDH83	2	FreeCamDH83	3

Supplemental Table S3. Continued

FreeCamDH84	1	FreeCamDH84	2	FreeCamDH84	4
FreeCamDH85	1	FreeCamDH85	2	FreeCamDH85	3
FreeCamDH86	1	FreeCamDH86	2	FreeCamDH86	4
FreeCamDH87	1	FreeCamDH87	2	FreeCamDH87	3
FreeCamDH88	1	FreeCamDH88	2	FreeCamDH88	3
FreeCamDH89	1	FreeCamDH89	2	FreeCamDH89	3
FreeCamDH90	1	FreeCamDH90	2	FreeCamDH90	3
FreeCamDH91	1	FreeCamDH91	2	FreeCamDH91	3
FreeCamDH92	1	FreeCamDH92	2	FreeCamDH92	3
FreeCamDH93	1	FreeCamDH93	2	FreeCamDH93	4
FreeCamDH94	1	FreeCamDH94	2	FreeCamDH94	4
FreeCamDH95	1	FreeCamDH95	2	FreeCamDH95	4
FreeCamDH96	1	FreeCamDH96	2	FreeCamDH96	3
FreeCamDH97	1	FreeCamDH97	2	FreeCamDH97	3
FreeCamDH98	1	FreeCamDH98	2	FreeCamDH98	3
FreeCamDH99	1	FreeCamDH99	2	FreeCamDH99	3
FreeCamDH100	1	FreeCamDH100	2	FreeCamDH100	3
FreeCamDH101	1	FreeCamDH101	2	FreeCamDH101	4
FreeCamDH102	1	FreeCamDH102	2	FreeCamDH102	3
FreeCamDH103	1	FreeCamDH103	2	FreeCamDH103	4
FreeCamDH104	1	FreeCamDH104	2	FreeCamDH104	3
FreeCamDH105	1	FreeCamDH105	2	FreeCamDH105	3

Supplemental Table S3. Continued

FreeCamDH106	1	FreeCamDH106	2	FreeCamDH106	3
FreeCamDH107	1	FreeCamDH107	2	FreeCamDH107	3
FreeCamDH108	1	FreeCamDH108	2	FreeCamDH108	3
FreeCamDH109	1	FreeCamDH109	2	FreeCamDH109	4
FreeCamDH110	1	FreeCamDH110	2	FreeCamDH110	3
FreeCamDH111	1	FreeCamDH111	2	FreeCamDH111	4
FreeCamDH112	1	FreeCamDH112	2	FreeCamDH112	4
FreeCamDH113	1	FreeCamDH113	2	FreeCamDH113	3
FreeCamDH114	1	FreeCamDH114	2	FreeCamDH114	4
FreeCamDH115	1	FreeCamDH115	2	FreeCamDH115	3
FreeCamDH116	1	FreeCamDH116	2	FreeCamDH116	3
FreeCamDH117	1	FreeCamDH117	2	FreeCamDH117	3
FreeCamDH118	1	FreeCamDH118	2	FreeCamDH118	3
FreeCamDH119	1	FreeCamDH119	2	FreeCamDH119	3
FreeCamDH120	1	FreeCamDH120	2	FreeCamDH120	3
FreeCamDH121	1	FreeCamDH121	2	FreeCamDH121	3
FreeCamDH122	1	FreeCamDH122	2	FreeCamDH122	3
FreeCamDH123	1	FreeCamDH123	2	FreeCamDH123	3
FreeCamDH124	1	FreeCamDH124	2	FreeCamDH124	4
FreeCamDH125	1	FreeCamDH125	2	FreeCamDH125	4
FreeCamDH126	1	FreeCamDH126	2	FreeCamDH126	3
FreeCamDH127	1	FreeCamDH127	2	FreeCamDH127	4

Supplemental Table S3. Continued

FreeCamDH128	1	FreeCamDH128	2	FreeCamDH128	3
FreeCamDH129	1	FreeCamDH129	2	FreeCamDH129	4
FreeCamDH130	1	FreeCamDH130	2	FreeCamDH130	3
FreeCamDH131	1	FreeCamDH131	2	FreeCamDH131	4
FreeCamDH132	1	FreeCamDH132	2	FreeCamDH132	3
FreeCamDH133	1	FreeCamDH133	2	FreeCamDH133	4
FreeCamDH134	1	FreeCamDH134	2	FreeCamDH134	3
FreeCamDH135	1	FreeCamDH135	2	FreeCamDH135	3
FreeCamDH136	1	FreeCamDH136	2	FreeCamDH136	3
FreeCamDH137	1	FreeCamDH137	2	FreeCamDH137	4
FreeCamDH138	1	FreeCamDH138	2	FreeCamDH138	4
FreeCamDH139	1	FreeCamDH139	2	FreeCamDH139	3
FreeCamDH140	1	FreeCamDH140	2	FreeCamDH140	3
FreeCamDH141	1	FreeCamDH141	2	FreeCamDH141	4
FreeCamDH142	1	FreeCamDH142	2	FreeCamDH142	3
FreeCamDH143	1	FreeCamDH143	2	FreeCamDH143	3
FreeCamDH144	1	FreeCamDH144	2	FreeCamDH144	3
FreeCamDH145	1	FreeCamDH145	2	FreeCamDH145	3
FreeCamDH146	1	FreeCamDH146	2	FreeCamDH146	4
FreeCamDH147	1	FreeCamDH147	2	FreeCamDH147	3
FreeCamDH148	1	FreeCamDH148	2	FreeCamDH148	4
FreeCamDH149	1	FreeCamDH149	2	FreeCamDH149	4

Supplemental Table S3. Continued

FreeCamDH150	1	FreeCamDH150	2	FreeCamDH150	4
FreeCamDH151	1	FreeCamDH151	2	FreeCamDH151	4
FreeCamDH152	4	FreeCamDH152	2	FreeCamDH152	3
FreeCamDH153	1	FreeCamDH153	2	FreeCamDH153	4
FreeCamDH154	1	FreeCamDH154	2	FreeCamDH154	4
FreeCamDH155	1	FreeCamDH155	2	FreeCamDH155	4
FreeCamDH156	1	FreeCamDH156	2	FreeCamDH156	3
FreeCamDH157	1	FreeCamDH157	2	FreeCamDH157	3
FreeCamDH158	1	FreeCamDH158	2	FreeCamDH158	3
FreeCamDH159	1	FreeCamDH159	2	FreeCamDH159	4
FreeCamDH160	1	FreeCamDH160	2	FreeCamDH160	3
FreeCamDH161	1	FreeCamDH161	2	FreeCamDH161	4
FreeCamDH162	1	FreeCamDH162	2	FreeCamDH162	3
FreeCamDH163	1	FreeCamDH163	2	FreeCamDH163	4
FreeCamDH164	1	FreeCamDH164	2	FreeCamDH164	4
FreeCamDH165	1	FreeCamDH165	2	FreeCamDH165	3
FreeCamDH166	1	FreeCamDH166	2	FreeCamDH166	4
FreeCamDH167	1	FreeCamDH167	2	FreeCamDH167	4
FreeCamDH168	1	FreeCamDH168	2	FreeCamDH168	3
FreeCamDH169	1	FreeCamDH169	2	FreeCamDH169	3
FreeCamDH170	1	FreeCamDH170	2	FreeCamDH170	3

Supplemental Table S3. Continued

FreeCamDH171	1	FreeCamDH171	2	FreeCamDH171	4
FreeCamDH172	1	FreeCamDH172	2	FreeCamDH172	3
FreeCamDH173	1	FreeCamDH173	2	FreeCamDH173	3
FreeCamDH174	1	FreeCamDH174	2	FreeCamDH174	3
K-means cluster means with 4 clusters of sizes 171, 174, 101, 76 respectively.					
CLUSTER	**TRAITS**				
(k)	**AE**	**AD**	**PH**	**LODG**	**GYLD**
1	-0.4161795	1.3130749	-1.4054676	-0.2323396	0.4162267
2	0.2033569	-0.7987906	0.7384909	0.2127418	-1.3454939
3	0.5339554	-0.5017297	0.6227162	-0.7543465	0.9567522
4	-0.2387749	-0.4588362	0.6439895	1.038184	0.8724896
The phenotypic means were calculated for lines in each cluster based on five traits measured.					
CLUSTER	**TRAITS**				
(k)	**AE (1-9)**	**AD (Julian)**	**PH (cm)**	**LODG (0-9)**	**GYLD (kg/ha)**
1	5	149.1	NA	3.2	3826.0
2	5.6	141.1	103.1	4.3	NA
3	6	142.2	99.5	1.9	4988.0
4	5.2	142.4	99.8	6.2	4804.0

Trait abbreviations; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield.
NA, not available.

Supplemental Table S4.1 Original data showing traits measured on population conducted as single replication at Lincoln in 2020.

REP	ENTRY	IBLOC	YEAR	LOC	EXP	NAME	NEW NAME	PLOT	AE	AD	LODG	GYLD
0	1	NA	2020	LIM	FxC20	FreeCamDH1	FreeCamDH1	4501	5	151	4.5	3658.4
0	2	NA	2020	LIM	FxC20	FreeCamDH2	FreeCamDH2	4502	5	149	6	4115.7
0	3	NA	2020	LIM	FxC20	FreeCamDH3	FreeCamDH3	4503	5	150	7.5	3745.8
0	4	NA	2020	LIM	FxC20	FreeCamDH4	FreeCamDH4	4504	4	149	6	4048.4
0	5	NA	2020	LIM	FxC20	FreeCamDH5	FreeCamDH5	4505	4	150	7.5	3093.5
0	6	NA	2020	LIM	FxC20	FreeCamDH6	FreeCamDH6	4506	5	150	6	3692
0	7	NA	2020	LIM	FxC20	FreeCamDH7	FreeCamDH7	4507	4	151	6	2737
0	8	NA	2020	LIM	FxC20	FreeCamDH8	FreeCamDH8	4508	7	145	0	4794.9
0	9	NA	2020	LIM	FxC20	FreeCamDH9	FreeCamDH9	4509	3	150	6	3584.4
0	10	NA	2020	LIM	FxC20	FreeCamDH10	FreeCamDH10	4510	4	152	7.5	3322.1
0	11	NA	2020	LIM	FxC20	FreeCamDH11	FreeCamDH11	4511	5	151	1.5	3766
0	12	NA	2020	LIM	FxC20	FreeCamDH12	FreeCamDH12	4512	4	149	4.5	3416.3
0	13	NA	2020	LIM	FxC20	FreeCamDH13	FreeCamDH13	4513	6	148	4.5	4095.5
0	14	NA	2020	LIM	FxC20	FreeCamDH14	FreeCamDH14	4514	4	148	7.5	3940.8
0	15	NA	2020	LIM	FxC20	FreeCamDH15	FreeCamDH15	4515	4	150	3	1923.3
0	16	NA	2020	LIM	FxC20	FreeCamDH16	FreeCamDH16	4516	4	149	4.5	3517.1
0	17	NA	2020	LIM	FxC20	FreeCamDH17	FreeCamDH17	4517	4	148	6	4310.7
0	18	NA	2020	LIM	FxC20	FreeCamDH18	FreeCamDH18	4518	5	147	3	4048.4
0	19	NA	2020	LIM	FxC20	FreeCamDH19	FreeCamDH19	4519	5	151	6	2508.4
0	20	NA	2020	LIM	FxC20	FreeCamDH20	FreeCamDH20	4521	6	145	1.5	4472.1

Supplemental Table S4.1 Continued

0	21	NA	2020	LIM	FxC20	FreeCamDH21	FreeCamDH21	4522	7	150	3	3234.7
0	22	NA	2020	LIM	FxC20	FreeCamDH22	FreeCamDH22	4523	4	149	3	4115.7
0	23	NA	2020	LIM	FxC20	FreeCamDH23	FreeCamDH23	4524	5	149	1.5	4485.5
0	24	NA	2020	LIM	FxC20	FreeCamDH24	FreeCamDH24	4525	6	149	4.5	2824.5
0	25	NA	2020	LIM	FxC20	FreeCamDH25	FreeCamDH25	4526	4	153	6	692.6
0	26	NA	2020	LIM	FxC20	FreeCamDH26	FreeCamDH26	4527	7	151	3	2030.9
0	27	NA	2020	LIM	FxC20	FreeCamDH27	FreeCamDH27	4528	5	152	3	3591.1
0	28	NA	2020	LIM	FxC20	FreeCamDH28	FreeCamDH28	4529	4	150	1.5	3961
0	29	NA	2020	LIM	FxC20	FreeCamDH29	FreeCamDH29	4530	4	151	3	2844.6
0	30	NA	2020	LIM	FxC20	FreeCamDH30	FreeCamDH30	4531	5	148	3	3900.5
0	31	NA	2020	LIM	FxC20	FreeCamDH31	FreeCamDH31	4532	5	149	6	4048.4
0	32	NA	2020	LIM	FxC20	FreeCamDH32	FreeCamDH32	4533	3	151	6	4048.4
0	33	NA	2020	LIM	FxC20	FreeCamDH33	FreeCamDH33	4534	5	151	4.5	3766
0	34	NA	2020	LIM	FxC20	FreeCamDH34	FreeCamDH34	4535	5	150	4.5	4008.1
0	35	NA	2020	LIM	FxC20	FreeCamDH35	FreeCamDH35	4536	5	151	4.5	3819.8
0	36	NA	2020	LIM	FxC20	FreeCamDH36	FreeCamDH36	4537	6	150	6	4310.7
0	37	NA	2020	LIM	FxC20	FreeCamDH37	FreeCamDH37	4538	4	152	7.5	4519.2
0	38	NA	2020	LIM	FxC20	FreeCamDH38	FreeCamDH38	4539	4	151	1.5	3866.8
0	39	NA	2020	LIM	FxC20	FreeCamDH39	FreeCamDH39	4541	6	149	1.5	3281.8
0	40	NA	2020	LIM	FxC20	FreeCamDH40	FreeCamDH40	4542	7	151	1.5	3644.9
0	41	NA	2020	LIM	FxC20	FreeCamDH41	FreeCamDH41	4543	5	152	3	2333.5

Supplemental Table S4.1 Continued

0	42	NA	2020	LIM	FxC20	FreeCamDH42	FreeCamDH42	4544	6	150	3	3692
0	43	NA	2020	LIM	FxC20	FreeCamDH43	FreeCamDH43	4545	5	150	7.5	3819.8
0	44	NA	2020	LIM	FxC20	FreeCamDH44	FreeCamDH44	4546	6	151	4.5	2770.7
0	45	NA	2020	LIM	-	SD05W018	SD05W018	4547	9	149	0	4895.8
0	46	NA	2020	LIM	FxC20	FreeCamDH46	FreeCamDH45	4548	5	152	0	3940.8
0	47	NA	2020	LIM	FxC20	FreeCamDH47	FreeCamDH46	4549	6	152	1.5	5023.5
0	48	NA	2020	LIM	FxC20	FreeCamDH48	FreeCamDH47	4550	5	151	7.5	3409.5
0	49	NA	2020	LIM	FxC20	FreeCamDH49	FreeCamDH48	4551	0	150	1.5	2457.3
0	50	NA	2020	LIM	FxC20	FreeCamDH50	FreeCamDH49	4552	5	151	1.5	2770.7
0	51	NA	2020	LIM	FxC20	FreeCamDH51	FreeCamDH50	4553	3	148	3	3503.7
0	52	NA	2020	LIM	FxC20	FreeCamDH52	FreeCamDH51	4554	6	150	7.5	4431.7
0	53	NA	2020	LIM	FxC20	FreeCamDH53	FreeCamDH52	4555	5	148	1.5	5016.8
0	54	NA	2020	LIM	FxC20	FreeCamDH54	FreeCamDH53	4556	5	148	1.5	4256.9
0	55	NA	2020	LIM	FxC20	FreeCamDH55	FreeCamDH54	4557	5	150	3	2333.5
0	56	NA	2020	LIM	FxC20	FreeCamDH56	FreeCamDH55	4558	5	148	6	3093.5
0	57	NA	2020	LIM	FxC20	FreeCamDH57	FreeCamDH56	4559	6	146	7.5	3779.4
0	58	NA	2020	LIM	FxC20	FreeCamDH58	FreeCamDH57	4561	5	151	4.5	3819.8
0	59	NA	2020	LIM	FxC20	FreeCamDH59	FreeCamDH58	4562	6	148	1.5	3745.8
0	60	NA	2020	LIM	FxC20	FreeCamDH60	FreeCamDH59	4563	5	149	7.5	4438.5
0	61	NA	2020	LIM	FxC20	FreeCamDH61	FreeCamDH60	4564	4	150	4.5	4135.8
0	62	NA	2020	LIM	FxC20	FreeCamDH62	FreeCamDH61	4565	4	150	1.5	4404.8

Supplemental Table S4.1 Continued

0	63	NA	2020	LIM	FxC20	FreeCamDH63	FreeCamDH62	4566	4	149	0	3584.4
0	64	NA	2020	LIM	FxC20	FreeCamDH64	FreeCamDH63	4567	3	148	3	3819.8
0	65	NA	2020	LIM	FxC20	FreeCamDH65	FreeCamDH64	4568	5	148	3	4068.6
0	66	NA	2020	LIM	FxC20	FreeCamDH66	FreeCamDH65	4569	5	148	3	4203.1
0	67	NA	2020	LIM	FxC20	FreeCamDH67	FreeCamDH66	4570	5	151	0	3537.3
0	68	NA	2020	LIM	FxC20	FreeCamDH68	FreeCamDH67	4571	6	150	0	4297.2
0	69	NA	2020	LIM	FxC20	FreeCamDH69	FreeCamDH68	4572	6	150	1.5	3954.3
0	70	NA	2020	LIM	FxC20	FreeCamDH70	FreeCamDH69	4573	6	148	6	4317.4
0	71	NA	2020	LIM	FxC20	FreeCamDH71	FreeCamDH70	4574	5	148	6	4593.1
0	72	NA	2020	LIM	FxC20	FreeCamDH72	FreeCamDH71	4575	6	149	4.5	4223.3
0	73	NA	2020	LIM	FxC20	FreeCamDH73	FreeCamDH72	4576	7	149	1.5	3813
0	74	NA	2020	LIM	FxC20	FreeCamDH74	FreeCamDH73	4577	6	148	1.5	4256.9
0	75	NA	2020	LIM	FxC20	FreeCamDH75	FreeCamDH74	4578	6	148	3	4909.2
0	76	NA	2020	LIM	FxC20	FreeCamDH76	FreeCamDH75	4579	4	151	0	3887
0	77	NA	2020	LIM	FxC20	FreeCamDH77	FreeCamDH76	4581	5	150	6	3375.9
0	78	NA	2020	LIM	FxC20	FreeCamDH78	FreeCamDH77	4582	6	149	0	4176.2
0	79	NA	2020	LIM	FxC20	FreeCamDH79	FreeCamDH78	4583	6	151	0	4344.3
0	80	NA	2020	LIM	FxC20	FreeCamDH80	FreeCamDH79	4584	6	149	1.5	3779.4
0	81	NA	2020	LIM	FxC20	FreeCamDH81	FreeCamDH80	4585	4	149	1.5	3194.3
0	82	NA	2020	LIM	FxC20	FreeCamDH82	FreeCamDH81	4586	5	150	3	4082
0	83	NA	2020	LIM	FxC20	FreeCamDH83	FreeCamDH82	4587	4	151	6	3833.2

Supplemental Table S4.1 Continued

0	84	NA	2020	LIM	FxC20	FreeCamDH84	FreeCamDH83	4588	4	149	1.5	4122.4
0	85	NA	2020	LIM	FxC20	FreeCamDH85	FreeCamDH84	4589	5	150	0	4492.3
0	86	NA	2020	LIM	FxC20	FreeCamDH86	FreeCamDH85	4590	4	149	4.5	3974.4
0	87	NA	2020	LIM	FxC20	FreeCamDH87	FreeCamDH86	4591	6	149	6	4909.2
0	88	NA	2020	LIM	FxC20	FreeCamDH88	FreeCamDH87	4592	5	151	1.5	3537.3
0	89	NA	2020	LIM	FxC20	FreeCamDH89	FreeCamDH88	4593	4	151	1.5	3833.2
0	90	NA	2020	LIM	FxC20	FreeCamDH90	FreeCamDH89	4594	5	151	1.5	4539.3
0	91	NA	2020	LIM	FxC20	FreeCamDH91	FreeCamDH90	4595	4	149	0	3873.6
0	92	NA	2020	LIM	FxC20	FreeCamDH92	FreeCamDH91	4596	5	149	1.5	4236.7
0	93	NA	2020	LIM	FxC20	FreeCamDH93	FreeCamDH92	4597	6	148	0	3725.6
0	94	NA	2020	LIM	FxC20	FreeCamDH94	FreeCamDH93	4598	6	146	1.5	4720.9
0	95	NA	2020	LIM	FxC20	FreeCamDH95	FreeCamDH94	4599	4	151	0	3416.3
0	96	NA	2020	LIM	FxC20	FreeCamDH96	FreeCamDH95	4601	4	150	1.5	3819.8
0	97	NA	2020	LIM	FxC20	FreeCamDH97	FreeCamDH96	4602	0	152	1.5	598.5
0	98	NA	2020	LIM	FxC20	FreeCamDH98	FreeCamDH97	4603	4	150	1.5	3584.4
0	99	NA	2020	LIM	FxC20	FreeCamDH99	FreeCamDH98	4604	4	151	1.5	3692
0	100	NA	2020	LIM	FxC20	FreeCamDH100	FreeCamDH99	4605	5	150	3	3194.3
0	101	NA	2020	LIM	FxC20	FreeCamDH101	FreeCamDH100	4606	4	150	1.5	3530.6
0	102	NA	2020	LIM	FxC20	FreeCamDH102	FreeCamDH101	4607	5	150	7.5	3396.1
0	103	NA	2020	LIM	FxC20	FreeCamDH103	FreeCamDH102	4608	6	146	1.5	4068.6
0	104	NA	2020	LIM	FxC20	FreeCamDH104	FreeCamDH103	4609	7	146	4.5	4277.1

Supplemental Table S4.1 Continued

0	105	NA	2020	LIM	FxC20	FreeCamDH105	FreeCamDH104	4610	5	150	1.5	3416.3
0	106	NA	2020	LIM	FxC20	FreeCamDH106	FreeCamDH105	4611	5	151	1.5	4344.3
0	107	NA	2020	LIM	FxC20	FreeCamDH107	FreeCamDH106	4612	6	149	0	3981.2
0	108	NA	2020	LIM	FxC20	FreeCamDH108	FreeCamDH107	4613	4	145	1.5	3725.6
0	109	NA	2020	LIM	FxC20	FreeCamDH109	FreeCamDH108	4614	4	150	3	3671.8
0	110	NA	2020	LIM	FxC20	FreeCamDH110	FreeCamDH109	4615	4	149	1.5	3618
0	111	NA	2020	LIM	FxC20	FreeCamDH111	FreeCamDH110	4616	7	150	0	4008.1
0	112	NA	2020	LIM	FxC20	FreeCamDH112	FreeCamDH111	4617	3	150	3	3591.1
0	113	NA	2020	LIM	FxC20	FreeCamDH113	FreeCamDH112	4618	4	149	1.5	4014.8
0	114	NA	2020	LIM	FxC20	FreeCamDH114	FreeCamDH113	4619	5	149	1.5	4398.1
0	115	NA	2020	LIM	FxC20	FreeCamDH115	FreeCamDH114	4621	4	146	7.5	4774.7
0	116	NA	2020	LIM	FxC20	FreeCamDH116	FreeCamDH115	4622	6	145	0	4330.9
0	117	NA	2020	LIM	FxC20	FreeCamDH117	FreeCamDH116	4623	4	150	3	3604.6
0	118	NA	2020	LIM	FxC20	FreeCamDH118	FreeCamDH117	4624	4	152	1.5	3537.3
0	119	NA	2020	LIM	FxC20	FreeCamDH119	FreeCamDH118	4625	5	151	0	4297.2
0	120	NA	2020	LIM	FxC20	FreeCamDH120	FreeCamDH119	4626	6	145	1.5	3624.7
0	121	NA	2020	LIM	FxC20	FreeCamDH121	FreeCamDH120	4627	6	149	3	4243.4
0	122	NA	2020	LIM	FxC20	FreeCamDH122	FreeCamDH121	4628	5	150	3	3658.4
0	123	NA	2020	LIM	FxC20	FreeCamDH123	FreeCamDH122	4629	5	148	1.5	4061.9
0	124	NA	2020	LIM	FxC20	FreeCamDH124	FreeCamDH123	4630	5	150	3	3779.4
0	125	NA	2020	LIM	FxC20	FreeCamDH125	FreeCamDH124	4631	5	149	6	4458.6

Supplemental Table S4.1 Continued

0	126	NA	2020	LIM	FxC20	FreeCamDH126	FreeCamDH125	4632	5	148	7.5	4290.5
0	127	NA	2020	LIM	FxC20	FreeCamDH127	FreeCamDH126	4633	5	148	6	4828.5
0	128	NA	2020	LIM	FxC20	FreeCamDH128	FreeCamDH127	4634	6	145	7.5	4203.1
0	129	NA	2020	LIM	FxC20	FreeCamDH129	FreeCamDH128	4635	5	147	1.5	3981.2
0	130	NA	2020	LIM	FxC20	FreeCamDH130	FreeCamDH129	4636	4	152	3	4048.4
0	131	NA	2020	LIM	FxC20	FreeCamDH131	FreeCamDH130	4637	7	146	4.5	4593.1
0	132	NA	2020	LIM	FxC20	FreeCamDH132	FreeCamDH131	4638	6	148	7.5	3658.4
0	133	NA	2020	LIM	FxC20	FreeCamDH133	FreeCamDH132	4639	5	147	6	4525.9
0	134	NA	2020	LIM	FxC20	FreeCamDH134	FreeCamDH133	4641	5	149	6	3961
0	135	NA	2020	LIM	FxC20	FreeCamDH135	FreeCamDH134	4642	6	145	7.5	4297.2
0	136	NA	2020	LIM	FxC20	FreeCamDH136	FreeCamDH135	4643	5	150	3	4209.8
0	137	NA	2020	LIM	FxC20	FreeCamDH137	FreeCamDH136	4644	7	150	3	3940.8
0	138	NA	2020	LIM	FxC20	FreeCamDH138	FreeCamDH137	4645	5	149	1.5	4082
0	139	NA	2020	LIM	FxC20	FreeCamDH139	FreeCamDH138	4646	7	148	6	4431.7
0	140	NA	2020	LIM	FxC20	FreeCamDH140	FreeCamDH139	4647	4	150	4.5	3409.5
0	141	NA	2020	LIM	FxC20	FreeCamDH141	FreeCamDH140	4648	7	148	1.5	5050.4
0	142	NA	2020	LIM	FxC20	FreeCamDH142	FreeCamDH141	4649	5	148	1.5	4418.3
0	143	NA	2020	LIM	FxC20	FreeCamDH143	FreeCamDH142	4650	6	149	1.5	4223.3
0	144	NA	2020	LIM	FxC20	FreeCamDH144	FreeCamDH143	4651	5	148	3	4451.9
0	145	NA	2020	LIM	FxC20	FreeCamDH145	FreeCamDH144	4652	5	144	0	4828.5
0	146	NA	2020	LIM	FxC20	FreeCamDH146	FreeCamDH145	4653	5	145	3	4135.8

Supplemental Table S4.1 Continued

0	147	NA	2020	LIM	FxC20	FreeCamDH147	FreeCamDH146	4654	4	150	7.5	3759.2
0	148	NA	2020	LIM	FxC20	FreeCamDH148	FreeCamDH147	4655	5	148	1.5	4277.1
0	149	NA	2020	LIM	FxC20	FreeCamDH149	FreeCamDH148	4656	5	150	6	3745.8
0	150	NA	2020	LIM	FxC20	FreeCamDH150	FreeCamDH149	4657	5	148	7.5	3732.3
0	151	NA	2020	LIM	FxC20	FreeCamDH151	FreeCamDH150	4658	6	148	3	4404.8
0	152	NA	2020	LIM	FxC20	FreeCamDH152	FreeCamDH151	4659	4	149	0	4135.8
0	153	NA	2020	LIM	FxC20	FreeCamDH153	FreeCamDH152	4661	5	149	1.5	3342.3
0	154	NA	2020	LIM	FxC20	FreeCamDH154	FreeCamDH153	4662	6	144	7.5	3887
0	155	NA	2020	LIM	FxC20	FreeCamDH155	FreeCamDH154	4663	6	146	1.5	3833.2
0	156	NA	2020	LIM	FxC20	FreeCamDH156	FreeCamDH155	4664	6	148	4.5	3907.2
0	157	NA	2020	LIM	FxC20	FreeCamDH157	FreeCamDH156	4665	5	148	4.5	3497
0	158	NA	2020	LIM	FxC20	FreeCamDH158	FreeCamDH157	4666	5	149	1.5	3301.9
0	159	NA	2020	LIM	FxC20	FreeCamDH159	FreeCamDH158	4667	6	145	1.5	3766
0	160	NA	2020	LIM	FxC20	FreeCamDH160	FreeCamDH159	4668	4	150	3	4492.3
0	161	NA	2020	LIM	FxC20	FreeCamDH161	FreeCamDH160	4669	7	149	0	4768
0	162	NA	2020	LIM	FxC20	FreeCamDH162	FreeCamDH161	4670	4	150	1.5	4014.8
0	163	NA	2020	LIM	FxC20	FreeCamDH163	FreeCamDH162	4671	6	148	1.5	4115.7
0	164	NA	2020	LIM	FxC20	FreeCamDH164	FreeCamDH163	4672	4	150	6	3362.5
0	165	NA	2020	LIM	FxC20	FreeCamDH165	FreeCamDH164	4673	6	149	4.5	4599.9
0	166	NA	2020	LIM	FxC20	FreeCamDH166	FreeCamDH165	4674	5	149	3	4317.4
0	167	NA	2020	LIM	FxC20	FreeCamDH167	FreeCamDH166	4675	4	149	1.5	4243.4

Supplemental Table S4.1 Continued

0	168	NA	2020	LIM	FxC20	FreeCamDH168	FreeCamDH167	4676	5	151	1.5	3248.1
0	169	NA	2020	LIM	FxC20	FreeCamDH169	FreeCamDH168	4677	5	147	0	3940.8
0	170	NA	2020	LIM	FxC20	FreeCamDH170	FreeCamDH169	4678	0	151	1.5	3866.8
0	171	NA	2020	LIM	FxC20	FreeCamDH171	FreeCamDH170	4679	5	150	0	3900.5
0	172	NA	2020	LIM	FxC20	FreeCamDH172	FreeCamDH171	4681	6	149	4.5	4909.2
0	173	NA	2020	LIM	FxC20	FreeCamDH173	FreeCamDH172	4682	5	146	1.5	4317.4
0	174	NA	2020	LIM	FxC20	FreeCamDH174	FreeCamDH173	4683	2	144	0	2071.3
0	175	NA	2020	LIM	FxC20	FreeCamDH175	FreeCamDH174	4684	8	149	0	4485.5
0	176	NA	2020	LIM	-	TAM107	TAM107	4685	5	144	1.5	3745.8
0	177	NA	2020	LIM	-	NI15713	NI15713	4686	7	145	1.5	4095.5
0	178	NA	2020	LIM	-	Pete	Pete	4687	6	149	3	5050.4
0	179	NA	2020	LIM	-	Camelot	Camelot	4520	3	150	3	3732.3
0	179	NA	2020	LIM	-	Camelot	Camelot	4560	4	150	3	4169.5
0	179	NA	2020	LIM	-	Camelot	Camelot	4600	3	149	1.5	3981.2
0	179	NA	2020	LIM	-	Camelot	Camelot	4640	5	147	1.5	4720.9
0	179	NA	2020	LIM	-	Camelot	Camelot	4680	3	147	1.5	4169.5
0	180	NA	2020	LIM	-	Freeman	Freeman	4540	5	150	0	4290.5
0	180	NA	2020	LIM	-	Freeman	Freeman	4580	7	148	0	4451.9
0	180	NA	2020	LIM	-	Freeman	Freeman	4620	7	147	0	4243.4
0	180	NA	2020	LIM	-	Freeman	Freeman	4660	7	145	0	4915.9
0	180	NA	2020	LIM	-	Freeman	Freeman	4688	7	149	4.5	4135.8

Abbreviations: REP, replication; LOC, location; EXP, experiment; AE, anther extrusion; AD, days to anthesis; LODG, lodging; GYLD, grain yield.

Supplemental Table S4.2. Original data showing observations of traits measured at Lincoln experiment conducted with two replications in 2021.

REP	ENTRY	IBLOC	YEAR	LOC	EXP	NAME	NEW NAME	PLOT	AE	AD	PH	LODG
1	1	22	2021	LIM	FxC21	FreeCamDH1	FreeCamDH1	4607	6	143	104.14	5
1	2	27	2021	LIM	FxC21	FreeCamDH2	FreeCamDH2	4634	6	143	99.06	3
1	3	23	2021	LIM	FxC21	FreeCamDH3	FreeCamDH3	4615	3	139	106.68	8
1	4	24	2021	LIM	FxC21	FreeCamDH4	FreeCamDH4	4619	5	142	111.76	6
1	5	19	2021	LIM	FxC21	FreeCamDH5	FreeCamDH5	4594	6	144	99.06	7
1	6	23	2021	LIM	FxC21	FreeCamDH6	FreeCamDH6	4612	6	140	101.6	4
1	7	16	2021	LIM	FxC21	FreeCamDH7	FreeCamDH7	4576	6	141	104.14	1
1	8	9	2021	LIM	FxC21	FreeCamDH8	FreeCamDH8	4543	6	138	93.98	1
1	9	1	2021	LIM	FxC21	FreeCamDH9	FreeCamDH9	4504	4	141	114.3	0
1	10	19	2021	LIM	FxC21	FreeCamDH10	FreeCamDH10	4592	3	145	106.68	8
1	11	31	2021	LIM	FxC21	FreeCamDH11	FreeCamDH11	4654	6	140	104.14	6
1	12	13	2021	LIM	FxC21	FreeCamDH12	FreeCamDH12	4561	6	142	106.68	6
1	13	33	2021	LIM	FxC21	FreeCamDH13	FreeCamDH13	4664	7	143	81.28	8
1	14	8	2021	LIM	FxC21	FreeCamDH14	FreeCamDH14	4539	5	143	106.68	8
1	15	32	2021	LIM	FxC21	FreeCamDH15	FreeCamDH15	4658	7	141	104.14	4
1	16	5	2021	LIM	FxC21	FreeCamDH16	FreeCamDH16	4522	6	141	96.52	2
1	17	17	2021	LIM	FxC21	FreeCamDH17	FreeCamDH17	4582	5	141	114.3	6
1	18	36	2021	LIM	FxC21	FreeCamDH18	FreeCamDH18	4678	5	140	114.3	1
1	19	35	2021	LIM	FxC21	FreeCamDH19	FreeCamDH19	4672	4	141	99.06	7

Supplemental Table S4.2. Continued

1	20	5	2021	LIM	FxC21	FreeCamDH20	FreeCamDH20	4524	4	140	106.68	5
1	21	21	2021	LIM	FxC21	FreeCamDH21	FreeCamDH21	4603	7	142	99.06	2
1	22	9	2021	LIM	FxC21	FreeCamDH22	FreeCamDH22	4541	5	140	109.22	1
1	23	29	2021	LIM	FxC21	FreeCamDH23	FreeCamDH23	4644	6	139	101.6	0
1	24	1	2021	LIM	FxC21	FreeCamDH24	FreeCamDH24	4505	5	140	101.6	0
1	25	35	2021	LIM	FxC21	FreeCamDH25	FreeCamDH25	4673	7	139	111.76	3
1	26	9	2021	LIM	FxC21	FreeCamDH26	FreeCamDH26	4545	6	140	109.22	1
1	27	36	2021	LIM	FxC21	FreeCamDH27	FreeCamDH27	4679	8	141	106.68	1
1	28	34	2021	LIM	FxC21	FreeCamDH28	FreeCamDH28	4667	6	144	104.14	1
1	29	17	2021	LIM	FxC21	FreeCamDH29	FreeCamDH29	4581	7	140	106.68	2
1	30	8	2021	LIM	FxC21	FreeCamDH30	FreeCamDH30	4538	5	139	93.98	2
1	31	14	2021	LIM	FxC21	FreeCamDH31	FreeCamDH31	4568	6	140	104.14	6
1	32	21	2021	LIM	FxC21	FreeCamDH32	FreeCamDH32	4602	3	140	106.68	8
1	33	19	2021	LIM	FxC21	FreeCamDH33	FreeCamDH33	4595	5	140	106.68	2
1	34	29	2021	LIM	FxC21	FreeCamDH34	FreeCamDH34	4645	5	145	99.06	6
1	35	27	2021	LIM	FxC21	FreeCamDH35	FreeCamDH35	4635	7	141	106.68	6
1	36	29	2021	LIM	FxC21	FreeCamDH36	FreeCamDH36	4643	6	142	109.22	4
1	37	9	2021	LIM	FxC21	FreeCamDH37	FreeCamDH37	4544	5	140	106.68	6
1	38	26	2021	LIM	FxC21	FreeCamDH38	FreeCamDH38	4630	6	142	106.68	4
1	39	31	2021	LIM	FxC21	FreeCamDH39	FreeCamDH39	4653	6	140	106.68	3

Supplemental Table S4.2. Continued

1	40	17	2021	LIM	FxC21	FreeCamDH40	FreeCamDH40	4585	8	142	96.52	1
1	41	32	2021	LIM	FxC21	FreeCamDH41	FreeCamDH41	4656	6	140	109.22	6
1	42	5	2021	LIM	FxC21	FreeCamDH42	FreeCamDH42	4525	5	142	99.06	6
1	43	5	2021	LIM	FxC21	FreeCamDH43	FreeCamDH43	4523	4	143	106.68	6
1	44	13	2021	LIM	FxC21	FreeCamDH44	FreeCamDH44	4565	5	141	106.68	1
1	45	2	2021	LIM	-	SD05W018	SD05W018	4510	7	140	99.06	4
1	46	25	2021	LIM	FxC21	FreeCamDH46	FreeCamDH45	4625	7	143	106.68	5
1	47	34	2021	LIM	FxC21	FreeCamDH47	FreeCamDH46	4668	7	145	109.22	3
1	48	18	2021	LIM	FxC21	FreeCamDH48	FreeCamDH47	4590	5	140	121.92	8
1	49	12	2021	LIM	FxC21	FreeCamDH49	FreeCamDH48	4558	7	141	104.14	2
1	50	28	2021	LIM	FxC21	FreeCamDH50	FreeCamDH49	4636	4	142	101.6	4
1	51	8	2021	LIM	FxC21	FreeCamDH51	FreeCamDH50	4540	7	140	111.76	2
1	52	7	2021	LIM	FxC21	FreeCamDH52	FreeCamDH51	4532	5	141	93.98	1
1	53	6	2021	LIM	FxC21	FreeCamDH53	FreeCamDH52	4527	7	141	106.68	0
1	54	19	2021	LIM	FxC21	FreeCamDH54	FreeCamDH53	4591	7	141	101.6	1
1	55	25	2021	LIM	FxC21	FreeCamDH55	FreeCamDH54	4624	5	141	109.22	6
1	56	27	2021	LIM	FxC21	FreeCamDH56	FreeCamDH55	4632	6	139	101.6	6
1	57	22	2021	LIM	FxC21	FreeCamDH57	FreeCamDH56	4610	5	141	116.84	7
1	58	14	2021	LIM	FxC21	FreeCamDH58	FreeCamDH57	4566	5	140	121.92	8
1	59	18	2021	LIM	FxC21	FreeCamDH59	FreeCamDH58	4587	6	141	99.06	0
1	60	6	2021	LIM	FxC21	FreeCamDH60	FreeCamDH59	4528	4	141	106.68	8

Supplemental Table S4.2. Continued

1	61	11	2021	LIM	FxC21	FreeCamDH61	FreeCamDH60	4551	7	143	101.6	2
1	62	26	2021	LIM	FxC21	FreeCamDH62	FreeCamDH61	4628	5	143	99.06	5
1	63	12	2021	LIM	FxC21	FreeCamDH63	FreeCamDH62	4556	5	143	116.84	0
1	64	18	2021	LIM	FxC21	FreeCamDH64	FreeCamDH63	4588	5	143	104.14	8
1	65	1	2021	LIM	FxC21	FreeCamDH65	FreeCamDH64	4503	6	142	106.68	0
1	66	10	2021	LIM	FxC21	FreeCamDH66	FreeCamDH65	4546	6	141	111.76	6
1	67	26	2021	LIM	FxC21	FreeCamDH67	FreeCamDH66	4629	6	143	101.6	3
1	68	36	2021	LIM	FxC21	FreeCamDH68	FreeCamDH67	4676	6	140	104.14	2
1	69	8	2021	LIM	FxC21	FreeCamDH69	FreeCamDH68	4536	3	141	99.06	1
1	70	31	2021	LIM	FxC21	FreeCamDH70	FreeCamDH69	4652	5	145	109.22	5
1	71	4	2021	LIM	FxC21	FreeCamDH71	FreeCamDH70	4516	5	144	99.06	4
1	72	26	2021	LIM	FxC21	FreeCamDH72	FreeCamDH71	4626	5	142	99.06	8
1	73	2	2021	LIM	FxC21	FreeCamDH73	FreeCamDH72	4507	5	141	99.06	2
1	74	6	2021	LIM	FxC21	FreeCamDH74	FreeCamDH73	4526	8	139	104.14	2
1	75	5	2021	LIM	FxC21	FreeCamDH75	FreeCamDH74	4521	5	144	109.22	1
1	76	33	2021	LIM	FxC21	FreeCamDH76	FreeCamDH75	4665	5	141	101.6	8
1	77	35	2021	LIM	FxC21	FreeCamDH77	FreeCamDH76	4671	5	139	91.44	6
1	78	23	2021	LIM	FxC21	FreeCamDH78	FreeCamDH77	4611	5	143	99.06	2
1	79	20	2021	LIM	FxC21	FreeCamDH79	FreeCamDH78	4598	7	144	109.22	1
1	80	12	2021	LIM	FxC21	FreeCamDH80	FreeCamDH79	4557	5	142	96.52	5
1	81	6	2021	LIM	FxC21	FreeCamDH81	FreeCamDH80	4529	6	142	99.06	3

Supplemental Table S4.2. Continued

1	82	12	2021	LIM	FxC21	FreeCamDH82	FreeCamDH81	4560	5	139	109.22	6
1	83	36	2021	LIM	FxC21	FreeCamDH83	FreeCamDH82	4677	4	141	91.44	9
1	84	4	2021	LIM	FxC21	FreeCamDH84	FreeCamDH83	4519	6	141	93.98	1
1	85	10	2021	LIM	FxC21	FreeCamDH85	FreeCamDH84	4550	5	140	116.84	6
1	86	12	2021	LIM	FxC21	FreeCamDH86	FreeCamDH85	4559	6	143	104.14	6
1	87	19	2021	LIM	FxC21	FreeCamDH87	FreeCamDH86	4593	5	139	101.6	8
1	88	30	2021	LIM	FxC21	FreeCamDH88	FreeCamDH87	4650	5	140	99.06	2
1	89	3	2021	LIM	FxC21	FreeCamDH89	FreeCamDH88	4515	6	142	114.3	2
1	90	1	2021	LIM	FxC21	FreeCamDH90	FreeCamDH89	4502	7	142	96.52	0
1	91	2	2021	LIM	FxC21	FreeCamDH91	FreeCamDH90	4506	3	140	104.14	2
1	92	14	2021	LIM	FxC21	FreeCamDH92	FreeCamDH91	4570	7	143	104.14	4
1	93	33	2021	LIM	FxC21	FreeCamDH93	FreeCamDH92	4663	6	138	91.44	1
1	94	3	2021	LIM	FxC21	FreeCamDH94	FreeCamDH93	4512	5	140	104.14	8
1	95	20	2021	LIM	FxC21	FreeCamDH95	FreeCamDH94	4597	5	141	104.14	5
1	96	24	2021	LIM	FxC21	FreeCamDH96	FreeCamDH95	4617	5	140	104.14	8
1	97	3	2021	LIM	FxC21	FreeCamDH97	FreeCamDH96	4513	4	141	101.6	1
1	98	10	2021	LIM	FxC21	FreeCamDH98	FreeCamDH97	4547	7	142	111.76	4
1	99	10	2021	LIM	FxC21	FreeCamDH99	FreeCamDH98	4549	5	143	96.52	1
1	100	13	2021	LIM	FxC21	FreeCamDH100	FreeCamDH99	4563	7	144	109.22	2
1	101	22	2021	LIM	FxC21	FreeCamDH101	FreeCamDH100	4609	7	140	104.14	2
1	102	7	2021	LIM	FxC21	FreeCamDH102	FreeCamDH101	4535	5	140	101.6	9

Supplemental Table S4.2. Continued

1	103	33	2021	LIM	FxC21	FreeCamDH103	FreeCamDH102	4661	6	140	96.52	6
1	104	7	2021	LIM	FxC21	FreeCamDH104	FreeCamDH103	4533	6	140	106.68	5
1	105	23	2021	LIM	FxC21	FreeCamDH105	FreeCamDH104	4614	5	138	104.14	7
1	106	20	2021	LIM	FxC21	FreeCamDH106	FreeCamDH105	4600	6	143	111.76	5
1	107	35	2021	LIM	FxC21	FreeCamDH107	FreeCamDH106	4675	4	142	106.68	3
1	108	31	2021	LIM	FxC21	FreeCamDH108	FreeCamDH107	4655	5	143	96.52	6
1	109	21	2021	LIM	FxC21	FreeCamDH109	FreeCamDH108	4604	7	138	101.6	3
1	110	28	2021	LIM	FxC21	FreeCamDH110	FreeCamDH109	4639	5	140	101.6	1
1	111	17	2021	LIM	FxC21	FreeCamDH111	FreeCamDH110	4584	7	140	109.22	1
1	112	27	2021	LIM	FxC21	FreeCamDH112	FreeCamDH111	4633	5	140	104.14	8
1	113	28	2021	LIM	FxC21	FreeCamDH113	FreeCamDH112	4637	4	139	106.68	2
1	114	11	2021	LIM	FxC21	FreeCamDH114	FreeCamDH113	4552	6	140	101.6	1
1	115	34	2021	LIM	FxC21	FreeCamDH115	FreeCamDH114	4669	5	141	101.6	5
1	116	16	2021	LIM	FxC21	FreeCamDH116	FreeCamDH115	4579	6	142	96.52	6
1	117	18	2021	LIM	FxC21	FreeCamDH117	FreeCamDH116	4589	4	139	109.22	2
1	118	13	2021	LIM	FxC21	FreeCamDH118	FreeCamDH117	4562	7	143	114.3	1
1	119	22	2021	LIM	FxC21	FreeCamDH119	FreeCamDH118	4608	7	142	93.98	1
1	120	22	2021	LIM	FxC21	FreeCamDH120	FreeCamDH119	4606	8	138	101.6	8
1	121	16	2021	LIM	FxC21	FreeCamDH121	FreeCamDH120	4578	5	141	101.6	8
1	122	30	2021	LIM	FxC21	FreeCamDH122	FreeCamDH121	4646	5	141	101.6	5
1	123	14	2021	LIM	FxC21	FreeCamDH123	FreeCamDH122	4569	5	141	99.06	8

Supplemental Table S4.2. Continued

1	124	17	2021	LIM	FxC21	FreeCamDH124	FreeCamDH123	4583	6	139	109.22	8
1	125	15	2021	LIM	FxC21	FreeCamDH125	FreeCamDH124	4571	7	139	93.98	5
1	126	34	2021	LIM	FxC21	FreeCamDH126	FreeCamDH125	4666	3	141	111.76	7
1	127	15	2021	LIM	FxC21	FreeCamDH127	FreeCamDH126	4572	7	140	99.06	2
1	128	16	2021	LIM	FxC21	FreeCamDH128	FreeCamDH127	4577	5	143	104.14	6
1	129	16	2021	LIM	FxC21	FreeCamDH129	FreeCamDH128	4580	7	141	99.06	1
1	130	14	2021	LIM	FxC21	FreeCamDH130	FreeCamDH129	4567	6	143	111.76	6
1	131	18	2021	LIM	FxC21	FreeCamDH131	FreeCamDH130	4586	7	139	99.06	1
1	132	3	2021	LIM	FxC21	FreeCamDH132	FreeCamDH131	4514	6	139	96.52	5
1	133	15	2021	LIM	FxC21	FreeCamDH133	FreeCamDH132	4574	6	139	101.6	2
1	134	26	2021	LIM	FxC21	FreeCamDH134	FreeCamDH133	4627	5	142	104.14	3
1	135	11	2021	LIM	FxC21	FreeCamDH135	FreeCamDH134	4555	4	140	93.98	7
1	136	29	2021	LIM	FxC21	FreeCamDH136	FreeCamDH135	4641	7	142	104.14	3
1	137	36	2021	LIM	FxC21	FreeCamDH137	FreeCamDH136	4680	7	142	99.06	2
1	138	28	2021	LIM	FxC21	FreeCamDH138	FreeCamDH137	4638	6	141	86.36	2
1	139	11	2021	LIM	FxC21	FreeCamDH139	FreeCamDH138	4554	7	141	99.06	8
1	140	2	2021	LIM	FxC21	FreeCamDH140	FreeCamDH139	4509	6	139	96.52	1
1	141	32	2021	LIM	FxC21	FreeCamDH141	FreeCamDH140	4659	7	143	96.52	4
1	142	11	2021	LIM	FxC21	FreeCamDH142	FreeCamDH141	4553	5	139	114.3	7
1	143	25	2021	LIM	FxC21	FreeCamDH143	FreeCamDH142	4623	6	141	106.68	6
1	144	32	2021	LIM	FxC21	FreeCamDH144	FreeCamDH143	4657	6	139	101.6	5

Supplemental Table S4.2. Continued

1	145	9	2021	LIM	FxC21	FreeCamDH145	FreeCamDH144	4542	6	142	96.52	0
1	146	25	2021	LIM	FxC21	FreeCamDH146	FreeCamDH145	4622	5	140	106.68	7
1	147	30	2021	LIM	FxC21	FreeCamDH147	FreeCamDH146	4648	5	145	99.06	8
1	148	3	2021	LIM	FxC21	FreeCamDH148	FreeCamDH147	4511	6	143	101.6	3
1	149	30	2021	LIM	FxC21	FreeCamDH149	FreeCamDH148	4649	3	142	109.22	8
1	150	21	2021	LIM	FxC21	FreeCamDH150	FreeCamDH149	4605	5	144	96.52	7
1	151	27	2021	LIM	FxC21	FreeCamDH151	FreeCamDH150	4631	5	141	106.68	6
1	152	24	2021	LIM	FxC21	FreeCamDH152	FreeCamDH151	4620	6	143	114.3	6
1	153	24	2021	LIM	FxC21	FreeCamDH153	FreeCamDH152	4616	5	140	99.06	6
1	154	1	2021	LIM	FxC21	FreeCamDH154	FreeCamDH153	4501	6	142	109.22	6
1	155	4	2021	LIM	FxC21	FreeCamDH155	FreeCamDH154	4517	6	140	106.68	5
1	156	28	2021	LIM	FxC21	FreeCamDH156	FreeCamDH155	4640	6	144	96.52	7
1	157	15	2021	LIM	FxC21	FreeCamDH157	FreeCamDH156	4573	6	139	93.98	3
1	158	24	2021	LIM	FxC21	FreeCamDH158	FreeCamDH157	4618	4	141	101.6	8
1	159	25	2021	LIM	FxC21	FreeCamDH159	FreeCamDH158	4621	7	139	111.76	3
1	160	13	2021	LIM	FxC21	FreeCamDH160	FreeCamDH159	4564	6	142	111.76	8
1	161	34	2021	LIM	FxC21	FreeCamDH161	FreeCamDH160	4670	8	142	104.14	1
1	162	31	2021	LIM	FxC21	FreeCamDH162	FreeCamDH161	4651	5	141	104.14	3
1	163	7	2021	LIM	FxC21	FreeCamDH163	FreeCamDH162	4531	7	140	119.38	2
1	164	32	2021	LIM	FxC21	FreeCamDH164	FreeCamDH163	4660	6	139	109.22	6
1	165	10	2021	LIM	FxC21	FreeCamDH165	FreeCamDH164	4548	7	140	99.06	5

Supplemental Table S4.2. Continued

1	166	29	2021	LIM	FxC21	FreeCamDH166	FreeCamDH165	4642	6	144	101.6	1
1	167	20	2021	LIM	FxC21	FreeCamDH167	FreeCamDH166	4599	6	145	104.14	6
1	168	35	2021	LIM	FxC21	FreeCamDH168	FreeCamDH167	4674	3	138	88.9	8
1	169	4	2021	LIM	FxC21	FreeCamDH169	FreeCamDH168	4518	5	144	104.14	2
1	170	30	2021	LIM	FxC21	FreeCamDH170	FreeCamDH169	4647	4	140	111.76	6
1	171	23	2021	LIM	FxC21	FreeCamDH171	FreeCamDH170	4613	6	139	101.6	5
1	172	7	2021	LIM	FxC21	FreeCamDH172	FreeCamDH171	4534	4	139	116.84	5
1	173	33	2021	LIM	FxC21	FreeCamDH173	FreeCamDH172	4662	5	141	96.52	8
1	174	15	2021	LIM	FxC21	FreeCamDH174	FreeCamDH173	4575	3	138	104.14	1
1	175	2	2021	LIM	FxC21	FreeCamDH175	FreeCamDH174	4508	8	143	114.3	0
1	176	6	2021	LIM	-	Camelot	Camelot	4530	4	144	109.22	3
1	177	8	2021	LIM	-	Freeman	Freeman	4537	6	138	111.76	5
1	178	20	2021	LIM	-	TAM107	TAM107	4596	6	139	109.22	1
1	179	21	2021	LIM	-	NI15713	NI15713	4601	6	140	104.14	7
1	180	4	2021	LIM	-	Pete	Pete	4520	3	140	101.6	1
2	1	11	2021	LIM	FxC21	FreeCamDH1	FreeCamDH1	4735	7	144	101.6	7
2	2	19	2021	LIM	FxC21	FreeCamDH2	FreeCamDH2	4771	7	142	101.6	2
2	3	7	2021	LIM	FxC21	FreeCamDH3	FreeCamDH3	4714	5	140	101.6	8
2	4	33	2021	LIM	FxC21	FreeCamDH4	FreeCamDH4	4841	6	141	104.14	7
2	5	5	2021	LIM	FxC21	FreeCamDH5	FreeCamDH5	4704	4	143	91.44	8
2	6	19	2021	LIM	FxC21	FreeCamDH6	FreeCamDH6	4774	5	140	10.16	3

Supplemental Table S4.2. Continued

2	7	21	2021	LIM	FxC21	FreeCamDH7	FreeCamDH7	4784	6	141	109.22	4
2	8	35	2021	LIM	FxC21	FreeCamDH8	FreeCamDH8	4852	6	139	91.44	2
2	9	32	2021	LIM	FxC21	FreeCamDH9	FreeCamDH9	4837	5	139	99.06	2
2	10	19	2021	LIM	FxC21	FreeCamDH10	FreeCamDH10	4773	3	143	106.68	8
2	11	33	2021	LIM	FxC21	FreeCamDH11	FreeCamDH11	4844	7	140	106.68	6
2	12	9	2021	LIM	FxC21	FreeCamDH12	FreeCamDH12	4721	4	140	106.68	3
2	13	21	2021	LIM	FxC21	FreeCamDH13	FreeCamDH13	4783	8	144	106.68	5
2	14	21	2021	LIM	FxC21	FreeCamDH14	FreeCamDH14	4785	5	143	109.22	7
2	15	2	2021	LIM	FxC21	FreeCamDH15	FreeCamDH15	4686	6	141	101.6	5
2	16	12	2021	LIM	FxC21	FreeCamDH16	FreeCamDH16	4738	5	140	104.14	5
2	17	19	2021	LIM	FxC21	FreeCamDH17	FreeCamDH17	4775	4	141	116.84	5
2	18	35	2021	LIM	FxC21	FreeCamDH18	FreeCamDH18	4854	6	141	104.14	2
2	19	31	2021	LIM	FxC21	FreeCamDH19	FreeCamDH19	4834	6	140	114.3	4
2	20	24	2021	LIM	FxC21	FreeCamDH20	FreeCamDH20	4798	5	141	111.76	7
2	21	25	2021	LIM	FxC21	FreeCamDH21	FreeCamDH21	4801	7	142	99.06	2
2	22	3	2021	LIM	FxC21	FreeCamDH22	FreeCamDH22	4691	5	141	106.68	6
2	23	26	2021	LIM	FxC21	FreeCamDH23	FreeCamDH23	4807	5	139	106.68	0
2	24	23	2021	LIM	FxC21	FreeCamDH24	FreeCamDH24	4795	6	141	104.14	2
2	25	6	2021	LIM	FxC21	FreeCamDH25	FreeCamDH25	4708	7	142	106.68	2
2	26	28	2021	LIM	FxC21	FreeCamDH26	FreeCamDH26	4816	6	141	109.22	2
2	27	3	2021	LIM	FxC21	FreeCamDH27	FreeCamDH27	4695	7	141	121.92	0

Supplemental Table S4.2. Continued

2	28	3	2021	LIM	FxC21	FreeCamDH28	FreeCamDH28	4692	6	144	101.6	2
2	29	36	2021	LIM	FxC21	FreeCamDH29	FreeCamDH29	4859	6	140	109.22	2
2	30	34	2021	LIM	FxC21	FreeCamDH30	FreeCamDH30	4846	6	140	88.9	2
2	31	10	2021	LIM	FxC21	FreeCamDH31	FreeCamDH31	4726	6	140	109.22	5
2	32	7	2021	LIM	FxC21	FreeCamDH32	FreeCamDH32	4713	6	141	104.14	8
2	33	25	2021	LIM	FxC21	FreeCamDH33	FreeCamDH33	4802	7	140	104.14	2
2	34	6	2021	LIM	FxC21	FreeCamDH34	FreeCamDH34	4710	5	141	99.06	7
2	35	23	2021	LIM	FxC21	FreeCamDH35	FreeCamDH35	4794	7	144	109.22	8
2	36	15	2021	LIM	FxC21	FreeCamDH36	FreeCamDH36	4755	6	143	96.52	4
2	37	1	2021	LIM	FxC21	FreeCamDH37	FreeCamDH37	4684	5	141	106.68	8
2	38	34	2021	LIM	FxC21	FreeCamDH38	FreeCamDH38	4850	5	141	104.14	1
2	39	32	2021	LIM	FxC21	FreeCamDH39	FreeCamDH39	4839	7	139	106.68	2
2	40	25	2021	LIM	FxC21	FreeCamDH40	FreeCamDH40	4805	8	143	96.52	1
2	41	26	2021	LIM	FxC21	FreeCamDH41	FreeCamDH41	4806	6	140	106.68	7
2	42	17	2021	LIM	FxC21	FreeCamDH42	FreeCamDH42	4762	5	141	99.06	7
2	43	27	2021	LIM	FxC21	FreeCamDH43	FreeCamDH43	4814	5	143	111.76	8
2	44	5	2021	LIM	FxC21	FreeCamDH44	FreeCamDH44	4702	6	140	104.14	3
2	45	31	2021	LIM	-	SD05W018	SD05W018	4831	8	143	109.22	4
2	46	9	2021	LIM	FxC21	FreeCamDH46	FreeCamDH45	4724	7	142	104.14	2
2	47	20	2021	LIM	FxC21	FreeCamDH47	FreeCamDH46	4780	7	141	101.6	5
2	48	20	2021	LIM	FxC21	FreeCamDH48	FreeCamDH47	4779	5	141	104.14	7

Supplemental Table S4.2. Continued

2	49	23	2021	LIM	FxC21	FreeCamDH49	FreeCamDH48	4791	8	140	93.98	1
2	50	12	2021	LIM	FxC21	FreeCamDH50	FreeCamDH49	4740	7	140	106.68	6
2	51	10	2021	LIM	FxC21	FreeCamDH51	FreeCamDH50	4730	5	139	109.22	3
2	52	4	2021	LIM	FxC21	FreeCamDH52	FreeCamDH51	4698	4	142	101.6	8
2	53	3	2021	LIM	FxC21	FreeCamDH53	FreeCamDH52	4694	4	139	96.52	0
2	54	9	2021	LIM	FxC21	FreeCamDH54	FreeCamDH53	4723	5	140	104.14	4
2	55	5	2021	LIM	FxC21	FreeCamDH55	FreeCamDH54	4701	7	140	106.68	7
2	56	7	2021	LIM	FxC21	FreeCamDH56	FreeCamDH55	4715	6	142	101.6	6
2	57	16	2021	LIM	FxC21	FreeCamDH57	FreeCamDH56	4760	5	140	106.68	8
2	58	11	2021	LIM	FxC21	FreeCamDH58	FreeCamDH57	4731	6	139	111.76	7
2	59	34	2021	LIM	FxC21	FreeCamDH59	FreeCamDH58	4847	5	141	91.44	2
2	60	35	2021	LIM	FxC21	FreeCamDH60	FreeCamDH59	4851	5	140	106.68	7
2	61	14	2021	LIM	FxC21	FreeCamDH61	FreeCamDH60	4747	7	142	104.14	8
2	62	20	2021	LIM	FxC21	FreeCamDH62	FreeCamDH61	4776	5	142	101.6	2
2	63	36	2021	LIM	FxC21	FreeCamDH63	FreeCamDH62	4858	6	142	96.52	1
2	64	11	2021	LIM	FxC21	FreeCamDH64	FreeCamDH63	4732	4	140	101.6	8
2	65	14	2021	LIM	FxC21	FreeCamDH65	FreeCamDH64	4750	7	142	106.68	3
2	66	24	2021	LIM	FxC21	FreeCamDH66	FreeCamDH65	4800	5	144	114.3	7
2	67	10	2021	LIM	FxC21	FreeCamDH67	FreeCamDH66	4729	6	141	96.52	2
2	68	16	2021	LIM	FxC21	FreeCamDH68	FreeCamDH67	4758	6	140	99.06	2
2	69	18	2021	LIM	FxC21	FreeCamDH69	FreeCamDH68	4768	6	142	104.14	2

Supplemental Table S4.2. Continued

2	70	13	2021	LIM	FxC21	FreeCamDH70	FreeCamDH69	4743	5	140	106.68	7
2	71	1	2021	LIM	FxC21	FreeCamDH71	FreeCamDH70	4681	5	142	88.9	6
2	72	11	2021	LIM	FxC21	FreeCamDH72	FreeCamDH71	4733	5	141	99.06	7
2	73	28	2021	LIM	FxC21	FreeCamDH73	FreeCamDH72	4820	6	141	106.68	4
2	74	16	2021	LIM	FxC21	FreeCamDH74	FreeCamDH73	4756	7	143	96.52	2
2	75	22	2021	LIM	FxC21	FreeCamDH75	FreeCamDH74	4788	4	145	106.68	2
2	76	18	2021	LIM	FxC21	FreeCamDH76	FreeCamDH75	4766	5	142	96.52	6
2	77	8	2021	LIM	FxC21	FreeCamDH77	FreeCamDH76	4718	4	141	106.68	8
2	78	5	2021	LIM	FxC21	FreeCamDH78	FreeCamDH77	4703	6	142	99.06	3
2	79	33	2021	LIM	FxC21	FreeCamDH79	FreeCamDH78	4843	7	141	106.68	0
2	80	14	2021	LIM	FxC21	FreeCamDH80	FreeCamDH79	4748	5	141	114.3	6
2	81	28	2021	LIM	FxC21	FreeCamDH81	FreeCamDH80	4818	4	141	104.14	1
2	82	29	2021	LIM	FxC21	FreeCamDH82	FreeCamDH81	4824	7	140	101.6	7
2	83	20	2021	LIM	FxC21	FreeCamDH83	FreeCamDH82	4778	5	142	109.22	7
2	84	15	2021	LIM	FxC21	FreeCamDH84	FreeCamDH83	4753	6	140	104.14	1
2	85	12	2021	LIM	FxC21	FreeCamDH85	FreeCamDH84	4737	6	139	116.84	8
2	86	19	2021	LIM	FxC21	FreeCamDH86	FreeCamDH85	4772	6	140	96.52	7
2	87	7	2021	LIM	FxC21	FreeCamDH87	FreeCamDH86	4712	5	139	99.06	8
2	88	18	2021	LIM	FxC21	FreeCamDH88	FreeCamDH87	4770	6	140	109.22	2
2	89	13	2021	LIM	FxC21	FreeCamDH89	FreeCamDH88	4745	7	142	101.6	2
2	90	36	2021	LIM	FxC21	FreeCamDH90	FreeCamDH89	4860	7	143	93.98	2

Supplemental Table S4.2. Continued

2	91	26	2021	LIM	FxC21	FreeCamDH91	FreeCamDH90	4809	4	141	101.6	1
2	92	34	2021	LIM	FxC21	FreeCamDH92	FreeCamDH91	4848	6	143	99.06	1
2	93	17	2021	LIM	FxC21	FreeCamDH93	FreeCamDH92	4763	5	141	99.06	1
2	94	32	2021	LIM	FxC21	FreeCamDH94	FreeCamDH93	4840	6	139	99.06	7
2	95	13	2021	LIM	FxC21	FreeCamDH95	FreeCamDH94	4744	5	142	101.6	6
2	96	13	2021	LIM	FxC21	FreeCamDH96	FreeCamDH95	4742	6	140	99.06	3
2	97	8	2021	LIM	FxC21	FreeCamDH97	FreeCamDH96	4716	5	141	99.06	1
2	98	27	2021	LIM	FxC21	FreeCamDH98	FreeCamDH97	4811	6	142	106.68	5
2	99	22	2021	LIM	FxC21	FreeCamDH99	FreeCamDH98	4787	4	146	99.06	2
2	100	4	2021	LIM	FxC21	FreeCamDH100	FreeCamDH99	4697	8	142	96.52	5
2	101	20	2021	LIM	FxC21	FreeCamDH101	FreeCamDH100	4777	6	143	109.22	2
2	102	9	2021	LIM	FxC21	FreeCamDH102	FreeCamDH101	4725	5	141	111.76	8
2	103	12	2021	LIM	FxC21	FreeCamDH103	FreeCamDH102	4739	6	139	101.6	2
2	104	12	2021	LIM	FxC21	FreeCamDH104	FreeCamDH103	4736	6	141	104.14	6
2	105	36	2021	LIM	FxC21	FreeCamDH105	FreeCamDH104	4857	5	139	99.06	2
2	106	14	2021	LIM	FxC21	FreeCamDH106	FreeCamDH105	4749	7	144	104.14	2
2	107	13	2021	LIM	FxC21	FreeCamDH107	FreeCamDH106	4741	7	143	93.98	0
2	108	14	2021	LIM	FxC21	FreeCamDH108	FreeCamDH107	4746	6	141	104.14	7
2	109	4	2021	LIM	FxC21	FreeCamDH109	FreeCamDH108	4699	6	141	104.14	6
2	110	22	2021	LIM	FxC21	FreeCamDH110	FreeCamDH109	4786	5	139	99.06	2
2	111	29	2021	LIM	FxC21	FreeCamDH111	FreeCamDH110	4823	6	141	99.06	1

Supplemental Table S4.2. Continued

2	112	29	2021	LIM	FxC21	FreeCamDH112	FreeCamDH111	4825	5	141	93.98	8
2	113	27	2021	LIM	FxC21	FreeCamDH113	FreeCamDH112	4812	5	141	111.76	7
2	114	33	2021	LIM	FxC21	FreeCamDH114	FreeCamDH113	4842	5	140	93.98	1
2	115	1	2021	LIM	FxC21	FreeCamDH115	FreeCamDH114	4683	5	142	99.06	7
2	116	30	2021	LIM	FxC21	FreeCamDH116	FreeCamDH115	4829	6	143	93.98	2
2	117	10	2021	LIM	FxC21	FreeCamDH117	FreeCamDH116	4727	6	138	111.76	2
2	118	24	2021	LIM	FxC21	FreeCamDH118	FreeCamDH117	4796	7	142	101.6	6
2	119	3	2021	LIM	FxC21	FreeCamDH119	FreeCamDH118	4693	8	141	101.6	1
2	120	34	2021	LIM	FxC21	FreeCamDH120	FreeCamDH119	4849	7	139	99.06	1
2	121	10	2021	LIM	FxC21	FreeCamDH121	FreeCamDH120	4728	7	144	106.68	7
2	122	17	2021	LIM	FxC21	FreeCamDH122	FreeCamDH121	4765	6	144	109.22	6
2	123	18	2021	LIM	FxC21	FreeCamDH123	FreeCamDH122	4769	5	141	106.68	8
2	124	7	2021	LIM	FxC21	FreeCamDH124	FreeCamDH123	4711	4	141	104.14	7
2	125	8	2021	LIM	FxC21	FreeCamDH125	FreeCamDH124	4720	6	140	91.44	5
2	126	35	2021	LIM	FxC21	FreeCamDH126	FreeCamDH125	4855	5	142	109.22	4
2	127	2	2021	LIM	FxC21	FreeCamDH127	FreeCamDH126	4689	7	143	93.98	7
2	128	18	2021	LIM	FxC21	FreeCamDH128	FreeCamDH127	4767	4	143	101.6	7
2	129	17	2021	LIM	FxC21	FreeCamDH129	FreeCamDH128	4764	8	140	96.52	1
2	130	30	2021	LIM	FxC21	FreeCamDH130	FreeCamDH129	4827	6	142	106.68	6
2	131	30	2021	LIM	FxC21	FreeCamDH131	FreeCamDH130	4826	5	138	99.06	1
2	132	33	2021	LIM	FxC21	FreeCamDH132	FreeCamDH131	4845	5	139	88.9	7

Supplemental Table S4.2. Continued

2	133	6	2021	LIM	FxC21	FreeCamDH133	FreeCamDH132	4706	6	141	93.98	5
2	134	16	2021	LIM	FxC21	FreeCamDH134	FreeCamDH133	4757	6	141	114.3	6
2	135	32	2021	LIM	FxC21	FreeCamDH135	FreeCamDH134	4836	6	140	106.68	5
2	136	31	2021	LIM	FxC21	FreeCamDH136	FreeCamDH135	4835	7	140	99.06	2
2	137	11	2021	LIM	FxC21	FreeCamDH137	FreeCamDH136	4734	8	140	104.14	6
2	138	17	2021	LIM	FxC21	FreeCamDH138	FreeCamDH137	4761	6	139	88.9	0
2	139	29	2021	LIM	FxC21	FreeCamDH139	FreeCamDH138	4821	7	141	104.14	7
2	140	1	2021	LIM	FxC21	FreeCamDH140	FreeCamDH139	4682	4	139	99.06	3
2	141	31	2021	LIM	FxC21	FreeCamDH141	FreeCamDH140	4832	7	142	99.06	3
2	142	23	2021	LIM	FxC21	FreeCamDH142	FreeCamDH141	4792	5	142	101.6	6
2	143	4	2021	LIM	FxC21	FreeCamDH143	FreeCamDH142	4696	7	141	104.14	4
2	144	28	2021	LIM	FxC21	FreeCamDH144	FreeCamDH143	4819	5	142	104.14	7
2	145	15	2021	LIM	FxC21	FreeCamDH145	FreeCamDH144	4754	5	141	101.6	0
2	146	25	2021	LIM	FxC21	FreeCamDH146	FreeCamDH145	4803	5	141	106.68	5
2	147	22	2021	LIM	FxC21	FreeCamDH147	FreeCamDH146	4790	4	142	106.68	6
2	148	6	2021	LIM	FxC21	FreeCamDH148	FreeCamDH147	4707	6	141	104.14	6
2	149	30	2021	LIM	FxC21	FreeCamDH149	FreeCamDH148	4830	4	143	116.84	5
2	150	9	2021	LIM	FxC21	FreeCamDH150	FreeCamDH149	4722	4	141	104.14	9
2	151	36	2021	LIM	FxC21	FreeCamDH151	FreeCamDH150	4856	6	143	99.06	5
2	152	6	2021	LIM	FxC21	FreeCamDH152	FreeCamDH151	4709	5	143	104.14	6
2	153	8	2021	LIM	FxC21	FreeCamDH153	FreeCamDH152	4719	6	141	96.52	4

Supplemental Table S4.2. Continued

2	154	29	2021	LIM	FxC21	FreeCamDH154	FreeCamDH153	4822	6	139	104.14	8
2	155	28	2021	LIM	FxC21	FreeCamDH155	FreeCamDH154	4817	6	141	109.22	5
2	156	21	2021	LIM	FxC21	FreeCamDH156	FreeCamDH155	4782	6	140	99.06	6
2	157	31	2021	LIM	FxC21	FreeCamDH157	FreeCamDH156	4833	5	139	101.6	2
2	158	2	2021	LIM	FxC21	FreeCamDH158	FreeCamDH157	4690	6	142	99.06	5
2	159	24	2021	LIM	FxC21	FreeCamDH159	FreeCamDH158	4799	6	140	106.68	6
2	160	27	2021	LIM	FxC21	FreeCamDH160	FreeCamDH159	4815	4	143	91.44	8
2	161	16	2021	LIM	FxC21	FreeCamDH161	FreeCamDH160	4759	7	142	96.52	2
2	162	23	2021	LIM	FxC21	FreeCamDH162	FreeCamDH161	4793	5	143	106.68	2
2	163	24	2021	LIM	FxC21	FreeCamDH163	FreeCamDH162	4797	6	142	114.3	6
2	164	15	2021	LIM	FxC21	FreeCamDH164	FreeCamDH163	4751	6	139	106.68	5
2	165	4	2021	LIM	FxC21	FreeCamDH165	FreeCamDH164	4700	4	140	99.06	6
2	166	2	2021	LIM	FxC21	FreeCamDH166	FreeCamDH165	4688	7	142	106.68	2
2	167	32	2021	LIM	FxC21	FreeCamDH167	FreeCamDH166	4838	4	143	101.6	5
2	168	2	2021	LIM	FxC21	FreeCamDH168	FreeCamDH167	4687	7	140	104.14	6
2	169	35	2021	LIM	FxC21	FreeCamDH169	FreeCamDH168	4853	5	142	96.52	1
2	170	21	2021	LIM	FxC21	FreeCamDH170	FreeCamDH169	4781	6	140	106.68	5
2	171	25	2021	LIM	FxC21	FreeCamDH171	FreeCamDH170	4804	5	141	91.44	5
2	172	27	2021	LIM	FxC21	FreeCamDH172	FreeCamDH171	4813	7	139	101.6	7
2	173	22	2021	LIM	FxC21	FreeCamDH173	FreeCamDH172	4789	6	139	106.68	4
2	174	26	2021	LIM	FxC21	FreeCamDH174	FreeCamDH173	4808	4	138	104.14	1

2	175	15	2021	LIM	FxC21	FreeCamDH175	FreeCamDH174	4752	8	143	106.68	2
2	176	1	2021	LIM	-	Camelot	Camelot	4685	4	142	101.6	7
2	177	30	2021	LIM	-	Freeman	Freeman	4828	6	139	106.68	7
2	178	8	2021	LIM	-	TAM107	TAM107	4717	5	139	104.14	0
2	179	5	2021	LIM	-	NI15713	NI15713	4705	6	140	111.76	7
2	180	26	2021	LIM	-	Pete	Pete	4810	3	137	101.6	1

Abbreviations: REP, replication; LOC, location; EXP, experiment; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging.

Supplemental Table S4.3. Original data showing observations of traits measured at Mead conducted with two replications in 2021.

REP	ENTRY	IBLOC	YEAR	LOC	EXP	NAME	NEW NAME	PLOT	AE	AD	PH	LODG	GYLD
1	1	12	2021	MD	FxC21	FreeCamDH1	FreeCamDH1	4919	6	144	101.6	8	5063.9
1	2	12	2021	MD	FxC21	FreeCamDH2	FreeCamDH2	4917	7	141	93.98	3	5662.4
1	3	21	2021	MD	FxC21	FreeCamDH3	FreeCamDH3	4961	5	144	93.98	8	3389.4
1	4	8	2021	MD	FxC21	FreeCamDH4	FreeCamDH4	4899	4	145	101.6	8	4014.8
1	5	5	2021	MD	FxC21	FreeCamDH5	FreeCamDH5	4882	5	145	99.06	8	3342.3
1	6	8	2021	MD	FxC21	FreeCamDH6	FreeCamDH6	4898	5	143	101.6	6	4593.1
1	7	7	2021	MD	FxC21	FreeCamDH7	FreeCamDH7	4891	4	145	96.52	7	4801.6
1	8	15	2021	MD	FxC21	FreeCamDH8	FreeCamDH8	4933	7	144	91.44	0	5965
1	9	6	2021	MD	FxC21	FreeCamDH9	FreeCamDH9	4888	5	144	106.68	7	4499
1	10	21	2021	MD	FxC21	FreeCamDH10	FreeCamDH10	4962	5	144	101.6	9	4008.1
1	11	2	2021	MD	FxC21	FreeCamDH11	FreeCamDH11	4870	5	142	96.52	2	5158
1	12	20	2021	MD	FxC21	FreeCamDH12	FreeCamDH12	4958	6	145	104.14	4	5050.4

Supplemental Table S4.3. Continued

1	13	27	2021	MD	FxC21	FreeCamDH13	FreeCamDH13	4991	8	141	101.6	3	4189.6
1	14	35	2021	MD	FxC21	FreeCamDH14	FreeCamDH14	5032	7	143	104.14	6	4768
1	15	27	2021	MD	FxC21	FreeCamDH15	FreeCamDH15	4994	7	140	106.68	0	4472.1
1	16	14	2021	MD	FxC21	FreeCamDH16	FreeCamDH16	4930	6	141	101.6	3	5131.1
1	17	25	2021	MD	FxC21	FreeCamDH17	FreeCamDH17	4984	6	142	111.76	8	5393.4
1	18	29	2021	MD	FxC21	FreeCamDH18	FreeCamDH18	5003	7	140	96.52	0	4364.5
1	19	34	2021	MD	FxC21	FreeCamDH19	FreeCamDH19	5026	7	142	106.68	8	4532.6
1	20	15	2021	MD	FxC21	FreeCamDH20	FreeCamDH20	4932	5	142	101.6	2	4868.9
1	21	29	2021	MD	FxC21	FreeCamDH21	FreeCamDH21	5001	5	143	99.06	3	5043.7
1	22	32	2021	MD	FxC21	FreeCamDH22	FreeCamDH22	5016	5	140	106.68	4	5111
1	23	24	2021	MD	FxC21	FreeCamDH23	FreeCamDH23	4979	6	140	106.68	0	4922.7
1	24	11	2021	MD	FxC21	FreeCamDH24	FreeCamDH24	4912	6	141	101.6	0	4458.6
1	25	26	2021	MD	FxC21	FreeCamDH25	FreeCamDH25	4986	6	140	101.6	4	3779.4
1	26	17	2021	MD	FxC21	FreeCamDH26	FreeCamDH26	4942	7	141	101.6	0	5010.1
1	27	10	2021	MD	FxC21	FreeCamDH27	FreeCamDH27	4910	6	143	109.22	2	4754.5
1	28	21	2021	MD	FxC21	FreeCamDH28	FreeCamDH28	4964	4	143	96.52	1	5353.1
1	29	20	2021	MD	FxC21	FreeCamDH29	FreeCamDH29	4957	6	142	104.14	2	4626.8
1	30	28	2021	MD	FxC21	FreeCamDH30	FreeCamDH30	4997	6	142	86.36	1	4909.2
1	31	3	2021	MD	FxC21	FreeCamDH31	FreeCamDH31	4872	6	143	109.22	8	3759.2
1	32	27	2021	MD	FxC21	FreeCamDH32	FreeCamDH32	4992	6	140	96.52	7	4499
1	33	19	2021	MD	FxC21	FreeCamDH33	FreeCamDH33	4955	5	139	101.6	0	5144.6

Supplemental Table S4.3. Continued

1	34	21	2021	MD	FxC21	FreeCamDH34	FreeCamDH34	4965	6	142	104.14	7	4855.4
1	35	29	2021	MD	FxC21	FreeCamDH35	FreeCamDH35	5005	7	142	101.6	8	4720.9
1	36	35	2021	MD	FxC21	FreeCamDH36	FreeCamDH36	5034	8	140	109.22	0	5050.4
1	37	31	2021	MD	FxC21	FreeCamDH37	FreeCamDH37	5011	5	140	91.44	8	4451.9
1	38	31	2021	MD	FxC21	FreeCamDH38	FreeCamDH38	5015	6	141	104.14	3	5238.7
1	39	29	2021	MD	FxC21	FreeCamDH39	FreeCamDH39	5004	5	139	96.52	3	4942.8
1	40	15	2021	MD	FxC21	FreeCamDH40	FreeCamDH40	4935	7	143	106.68	3	5918
1	41	32	2021	MD	FxC21	FreeCamDH41	FreeCamDH41	5019	5	140	111.76	2	5070.6
1	42	18	2021	MD	FxC21	FreeCamDH42	FreeCamDH42	4948	6	142	99.06	8	4694
1	43	36	2021	MD	FxC21	FreeCamDH43	FreeCamDH43	5037	6	143	99.06	8	4357.8
1	44	12	2021	MD	FxC21	FreeCamDH44	FreeCamDH44	4916	6	142	109.22	0	4606.6
1	45	30	2021	MD	-	SD05W018	SD05W018	5009	8	143	99.06	4	4344.3
1	46	14	2021	MD	FxC21	FreeCamDH46	FreeCamDH45	4926	8	145	96.52	4	5030.3
1	47	23	2021	MD	FxC21	FreeCamDH47	FreeCamDH46	4975	6	145	106.68	2	4687.3
1	48	20	2021	MD	FxC21	FreeCamDH48	FreeCamDH47	4959	4	142	93.98	9	4842
1	49	19	2021	MD	FxC21	FreeCamDH49	FreeCamDH48	4953	7	142	101.6	0	5353.1
1	50	36	2021	MD	FxC21	FreeCamDH50	FreeCamDH49	5039	4	142	101.6	7	5521.2
1	51	23	2021	MD	FxC21	FreeCamDH51	FreeCamDH50	4972	6	141	96.52	2	4949.6
1	52	19	2021	MD	FxC21	FreeCamDH52	FreeCamDH51	4951	6	141	93.98	8	4142.6
1	53	2	2021	MD	FxC21	FreeCamDH53	FreeCamDH52	4866	5	141	93.98	0	4687.3
1	54	9	2021	MD	FxC21	FreeCamDH54	FreeCamDH53	4903	6	142	93.98	2	4963

Supplemental Table S4.3. Continued

1	55	22	2021	MD	FxC21	FreeCamDH55	FreeCamDH54	4970	5	141	101.6	3	4485.5
1	56	24	2021	MD	FxC21	FreeCamDH56	FreeCamDH55	4978	7	143	99.06	7	4377.9
1	57	14	2021	MD	FxC21	FreeCamDH57	FreeCamDH56	4927	6	145	111.76	7	5016.8
1	58	34	2021	MD	FxC21	FreeCamDH58	FreeCamDH57	5030	6	140	106.68	5	4633.5
1	59	2	2021	MD	FxC21	FreeCamDH59	FreeCamDH58	4867	7	142	88.9	0	5655.7
1	60	36	2021	MD	FxC21	FreeCamDH60	FreeCamDH59	5040	7	141	99.06	8	5016.8
1	61	7	2021	MD	FxC21	FreeCamDH61	FreeCamDH60	4893	5	144	104.14	8	4330.9
1	62	35	2021	MD	FxC21	FreeCamDH62	FreeCamDH61	5035	7	142	104.14	3	5178.2
1	63	9	2021	MD	FxC21	FreeCamDH63	FreeCamDH62	4901	6	142	93.98	0	5258.9
1	64	4	2021	MD	FxC21	FreeCamDH64	FreeCamDH63	4880	4	146	99.06	7	4673.8
1	65	8	2021	MD	FxC21	FreeCamDH65	FreeCamDH64	4900	6	143	109.22	1	5077.3
1	66	23	2021	MD	FxC21	FreeCamDH66	FreeCamDH65	4974	5	142	104.14	6	5326.2
1	67	11	2021	MD	FxC21	FreeCamDH67	FreeCamDH66	4913	6	143	96.52	1	4552.8
1	68	22	2021	MD	FxC21	FreeCamDH68	FreeCamDH67	4966	7	142	91.44	3	5030.3
1	69	18	2021	MD	FxC21	FreeCamDH69	FreeCamDH68	4949	6	141	96.52	4	5595.2
1	70	28	2021	MD	FxC21	FreeCamDH70	FreeCamDH69	5000	6	141	104.14	4	5124.4
1	71	14	2021	MD	FxC21	FreeCamDH71	FreeCamDH70	4928	5	142	91.44	6	5749.8
1	72	6	2021	MD	FxC21	FreeCamDH72	FreeCamDH71	4886	6	143	96.52	8	4761.3
1	73	30	2021	MD	FxC21	FreeCamDH73	FreeCamDH72	5010	7	142	104.14	1	4969.7
1	74	23	2021	MD	FxC21	FreeCamDH74	FreeCamDH73	4971	7	140	99.06	1	4848.7
1	75	35	2021	MD	FxC21	FreeCamDH75	FreeCamDH74	5033	5	139	101.6	2	5265.6

Supplemental Table S4.3. Continued

1	76	22	2021	MD	FxC21	FreeCamDH76	FreeCamDH75	4968	7	139	88.9	6	4156
1	77	31	2021	MD	FxC21	FreeCamDH77	FreeCamDH76	5014	7	139	99.06	8	4862.1
1	78	34	2021	MD	FxC21	FreeCamDH78	FreeCamDH77	5029	5	142	104.14	2	4606.6
1	79	17	2021	MD	FxC21	FreeCamDH79	FreeCamDH78	4941	5	144	106.68	0	4586.4
1	80	3	2021	MD	FxC21	FreeCamDH80	FreeCamDH79	4873	5	142	99.06	8	4646.9
1	81	26	2021	MD	FxC21	FreeCamDH81	FreeCamDH80	4990	6	141	96.52	0	5581.7
1	82	16	2021	MD	FxC21	FreeCamDH82	FreeCamDH81	4936	4	141	101.6	8	4741.1
1	83	27	2021	MD	FxC21	FreeCamDH83	FreeCamDH82	4993	5	138	88.9	8	4734.4
1	84	22	2021	MD	FxC21	FreeCamDH84	FreeCamDH83	4967	7	141	91.44	3	5386.7
1	85	30	2021	MD	FxC21	FreeCamDH85	FreeCamDH84	5006	6	142	106.68	8	4310.7
1	86	1	2021	MD	FxC21	FreeCamDH86	FreeCamDH85	4861	6	140	111.76	0	5649
1	87	7	2021	MD	FxC21	FreeCamDH87	FreeCamDH86	4895	7	143	101.6	8	5063.9
1	88	33	2021	MD	FxC21	FreeCamDH88	FreeCamDH87	5022	6	141	106.68	0	5211.8
1	89	4	2021	MD	FxC21	FreeCamDH89	FreeCamDH88	4878	6	142	101.6	4	3409.5
1	90	8	2021	MD	FxC21	FreeCamDH90	FreeCamDH89	4896	7	141	99.06	4	5191.7
1	91	30	2021	MD	FxC21	FreeCamDH91	FreeCamDH90	5007	7	145	106.68	5	5427
1	92	8	2021	MD	FxC21	FreeCamDH92	FreeCamDH91	4897	6	141	96.52	0	4707.5
1	93	25	2021	MD	FxC21	FreeCamDH93	FreeCamDH92	4981	4	141	93.98	5	5507.7
1	94	9	2021	MD	FxC21	FreeCamDH94	FreeCamDH93	4902	7	141	101.6	4	5440.5
1	95	18	2021	MD	FxC21	FreeCamDH95	FreeCamDH94	4950	5	140	101.6	7	5050.4
1	96	28	2021	MD	FxC21	FreeCamDH96	FreeCamDH95	4999	6	140	101.6	3	4788.2

Supplemental Table S4.3. Continued

1	97	5	2021	MD	FxC21	FreeCamDH97	FreeCamDH96	4883	6	143	101.6	3	4754.5
1	98	12	2021	MD	FxC21	FreeCamDH98	FreeCamDH97	4920	7	142	106.68	3	5137.9
1	99	27	2021	MD	FxC21	FreeCamDH99	FreeCamDH98	4995	4	142	99.06	0	5003.4
1	100	16	2021	MD	FxC21	FreeCamDH100	FreeCamDH99	4938	3	146	96.52	2	4445.2
1	101	35	2021	MD	FxC21	FreeCamDH101	FreeCamDH100	5031	6	141	99.06	1	5521.2
1	102	10	2021	MD	FxC21	FreeCamDH102	FreeCamDH101	4908	4	146	96.52	8	4848.7
1	103	18	2021	MD	FxC21	FreeCamDH103	FreeCamDH102	4947	5	141	99.06	0	5514.5
1	104	1	2021	MD	FxC21	FreeCamDH104	FreeCamDH103	4864	5	143	99.06	5	5097.5
1	105	21	2021	MD	FxC21	FreeCamDH105	FreeCamDH104	4963	7	140	93.98	2	5104.2
1	106	11	2021	MD	FxC21	FreeCamDH106	FreeCamDH105	4915	6	144	101.6	0	4297.2
1	107	3	2021	MD	FxC21	FreeCamDH107	FreeCamDH106	4871	3	142	101.6	4	4196.4
1	108	1	2021	MD	FxC21	FreeCamDH108	FreeCamDH107	4865	5	145	93.98	2	5796.9
1	109	12	2021	MD	FxC21	FreeCamDH109	FreeCamDH108	4918	5	143	99.06	5	4963
1	110	2	2021	MD	FxC21	FreeCamDH110	FreeCamDH109	4868	6	143	78.74	4	5366.5
1	111	31	2021	MD	FxC21	FreeCamDH111	FreeCamDH110	5012	8	141	104.14	1	5380
1	112	25	2021	MD	FxC21	FreeCamDH112	FreeCamDH111	4982	5	142	96.52	9	5030.3
1	113	9	2021	MD	FxC21	FreeCamDH113	FreeCamDH112	4905	5	143	99.06	7	5534.6
1	114	3	2021	MD	FxC21	FreeCamDH114	FreeCamDH113	4874	6	142	91.44	2	4660.4
1	115	13	2021	MD	FxC21	FreeCamDH115	FreeCamDH114	4924	5	141	93.98	5	5689.3
1	116	10	2021	MD	FxC21	FreeCamDH116	FreeCamDH115	4906	8	142	96.52	0	5581.7
1	117	32	2021	MD	FxC21	FreeCamDH117	FreeCamDH116	5020	6	139	101.6	0	5225.3

Supplemental Table S4.3. Continued

1	118	6	2021	MD	FxC21	FreeCamDH118	FreeCamDH117	4889	7	143	101.6	6	4250.2
1	119	19	2021	MD	FxC21	FreeCamDH119	FreeCamDH118	4954	6	141	104.14	2	4902.5
1	120	34	2021	MD	FxC21	FreeCamDH120	FreeCamDH119	5028	4	139	96.52	0	3597.8
1	121	13	2021	MD	FxC21	FreeCamDH121	FreeCamDH120	4921	7	143	99.06	2	4606.6
1	122	4	2021	MD	FxC21	FreeCamDH122	FreeCamDH121	4877	5	143	106.68	5	3328.8
1	123	20	2021	MD	FxC21	FreeCamDH123	FreeCamDH122	4960	6	143	101.6	3	5527.9
1	124	9	2021	MD	FxC21	FreeCamDH124	FreeCamDH123	4904	6	141	99.06	3	4700.7
1	125	10	2021	MD	FxC21	FreeCamDH125	FreeCamDH124	4909	7	142	91.44	6	5406.9
1	126	16	2021	MD	FxC21	FreeCamDH126	FreeCamDH125	4937	5	143	114.3	5	5137.9
1	127	28	2021	MD	FxC21	FreeCamDH127	FreeCamDH126	4998	7	139	96.52	4	5366.5
1	128	14	2021	MD	FxC21	FreeCamDH128	FreeCamDH127	4929	4	143	104.14	8	3544
1	129	13	2021	MD	FxC21	FreeCamDH129	FreeCamDH128	4925	7	140	99.06	2	4223.3
1	130	18	2021	MD	FxC21	FreeCamDH130	FreeCamDH129	4946	6	145	106.68	6	4936.1
1	131	17	2021	MD	FxC21	FreeCamDH131	FreeCamDH130	4945	5	143	93.98	3	5460.7
1	132	20	2021	MD	FxC21	FreeCamDH132	FreeCamDH131	4956	5	140	96.52	7	3530.6
1	133	15	2021	MD	FxC21	FreeCamDH133	FreeCamDH132	4931	6	143	99.06	3	5857.4
1	134	30	2021	MD	FxC21	FreeCamDH134	FreeCamDH133	5008	6	141	91.44	5	5225.3
1	135	33	2021	MD	FxC21	FreeCamDH135	FreeCamDH134	5025	5	142	101.6	7	4788.2
1	136	33	2021	MD	FxC21	FreeCamDH136	FreeCamDH135	5023	6	145	96.52	2	4667.1
1	137	1	2021	MD	FxC21	FreeCamDH137	FreeCamDH136	4862	8	142	101.6	4	5252.2
1	138	5	2021	MD	FxC21	FreeCamDH138	FreeCamDH137	4885	5	141	81.28	6	5534.6

Supplemental Table S4.3. Continued

1	139	4	2021	MD	FxC21	FreeCamDH139	FreeCamDH138	4879	5	145	93.98	8	4667.1
1	140	22	2021	MD	FxC21	FreeCamDH140	FreeCamDH139	4969	6	142	96.52	1	4680.6
1	141	29	2021	MD	FxC21	FreeCamDH141	FreeCamDH140	5002	8	144	93.98	0	5097.5
1	142	24	2021	MD	FxC21	FreeCamDH142	FreeCamDH141	4980	4	142	96.52	0	5386.7
1	143	6	2021	MD	FxC21	FreeCamDH143	FreeCamDH142	4887	7	142	104.14	6	4317.4
1	144	36	2021	MD	FxC21	FreeCamDH144	FreeCamDH143	5038	5	142	96.52	6	4196.4
1	145	24	2021	MD	FxC21	FreeCamDH145	FreeCamDH144	4976	4	143	86.36	0	4902.5
1	146	7	2021	MD	FxC21	FreeCamDH146	FreeCamDH145	4894	6	142	99.06	7	5420.3
1	147	34	2021	MD	FxC21	FreeCamDH147	FreeCamDH146	5027	6	141	99.06	7	4169.5
1	148	28	2021	MD	FxC21	FreeCamDH148	FreeCamDH147	4996	5	144	93.98	2	4573
1	149	4	2021	MD	FxC21	FreeCamDH149	FreeCamDH148	4876	5	143	109.22	8	4035
1	150	24	2021	MD	FxC21	FreeCamDH150	FreeCamDH149	4977	5	140	99.06	9	3019.5
1	151	5	2021	MD	FxC21	FreeCamDH151	FreeCamDH150	4881	5	142	96.52	6	3106.9
1	152	15	2021	MD	FxC21	FreeCamDH152	FreeCamDH151	4934	4	145	106.68	1	4532.6
1	153	11	2021	MD	FxC21	FreeCamDH153	FreeCamDH152	4911	7	142	104.14	0	5144.6
1	154	5	2021	MD	FxC21	FreeCamDH154	FreeCamDH153	4884	6	142	104.14	9	5265.6
1	155	36	2021	MD	FxC21	FreeCamDH155	FreeCamDH154	5036	5	141	101.6	4	4539.3
1	156	13	2021	MD	FxC21	FreeCamDH156	FreeCamDH155	4923	5	143	99.06	6	4808.3
1	157	25	2021	MD	FxC21	FreeCamDH157	FreeCamDH156	4983	7	143	109.22	5	4243.4
1	158	1	2021	MD	FxC21	FreeCamDH158	FreeCamDH157	4863	7	141	96.52	4	5393.4
1	159	7	2021	MD	FxC21	FreeCamDH159	FreeCamDH158	4892	5	140	101.6	5	3577.7

Supplemental Table S4.3. Continued

1	160	17	2021	MD	FxC21	FreeCamDH160	FreeCamDH159	4944	4	145	99.06	7	4868.9
1	161	32	2021	MD	FxC21	FreeCamDH161	FreeCamDH160	5017	7	140	101.6	0	5292.5
1	162	25	2021	MD	FxC21	FreeCamDH162	FreeCamDH161	4985	5	143	101.6	7	5057.2
1	163	10	2021	MD	FxC21	FreeCamDH163	FreeCamDH162	4907	7	142	101.6	3	5460.7
1	164	6	2021	MD	FxC21	FreeCamDH164	FreeCamDH163	4890	3	144	91.44	7	5581.7
1	165	33	2021	MD	FxC21	FreeCamDH165	FreeCamDH164	5021	5	142	104.14	7	5023.5
1	166	26	2021	MD	FxC21	FreeCamDH166	FreeCamDH165	4987	5	145	99.06	0	5763.3
1	167	3	2021	MD	FxC21	FreeCamDH167	FreeCamDH166	4875	4	143	106.68	5	4135.8
1	168	16	2021	MD	FxC21	FreeCamDH168	FreeCamDH167	4939	6	142	96.52	8	4983.2
1	169	19	2021	MD	FxC21	FreeCamDH169	FreeCamDH168	4952	6	142	96.52	0	5447.2
1	170	11	2021	MD	FxC21	FreeCamDH170	FreeCamDH169	4914	5	143	111.76	0	4727.6
1	171	26	2021	MD	FxC21	FreeCamDH171	FreeCamDH170	4989	4	140	96.52	3	5205.1
1	172	32	2021	MD	FxC21	FreeCamDH172	FreeCamDH171	5018	4	138	109.22	3	5359.8
1	173	2	2021	MD	FxC21	FreeCamDH173	FreeCamDH172	4869	7	141	81.28	0	5891.1
1	174	17	2021	MD	FxC21	FreeCamDH174	FreeCamDH173	4943	3	138	91.44	0	3510.4
1	175	31	2021	MD	FxC21	FreeCamDH175	FreeCamDH174	5013	8	143	101.6	0	4741.1
1	176	33	2021	MD	-	Camelot	Camelot	5024	3	138	104.14	0	5312.7
1	177	23	2021	MD	-	Freeman	Freeman	4973	6	140	104.14	5	5285.8
1	178	26	2021	MD	-	TAM107	TAM107	4988	6	139	96.52	0	5137.9
1	179	16	2021	MD	-	NI15713	NI15713	4940	7	140	99.06	6	4162.7
1	180	13	2021	MD	-	Pete	Pete	4922	3	138	88.9	0	3732.3

Supplemental Table S4.3. Continued

2	1	32	2021	MD	FxC21	FreeCamDH1	FreeCamDH1	5199	8	139	109.22	4	5507.7
2	2	16	2021	MD	FxC21	FreeCamDH2	FreeCamDH2	5117	7	143	104.14	5	6166.8
2	3	16	2021	MD	FxC21	FreeCamDH3	FreeCamDH3	5118	3	140	91.44	7	4626.8
2	4	11	2021	MD	FxC21	FreeCamDH4	FreeCamDH4	5092	5	143	106.68	8	4815.1
2	5	29	2021	MD	FxC21	FreeCamDH5	FreeCamDH5	5185	6	145	99.06	5	4774.7
2	6	21	2021	MD	FxC21	FreeCamDH6	FreeCamDH6	5144	4	142	96.52	6	5245.5
2	7	25	2021	MD	FxC21	FreeCamDH7	FreeCamDH7	5165	5	143	99.06	7	4774.7
2	8	34	2021	MD	FxC21	FreeCamDH8	FreeCamDH8	5206	7	142	86.36	0	5709.5
2	9	11	2021	MD	FxC21	FreeCamDH9	FreeCamDH9	5093	6	143	104.14	6	5272.4
2	10	33	2021	MD	FxC21	FreeCamDH10	FreeCamDH10	5204	6	142	109.22	7	3866.8
2	11	26	2021	MD	FxC21	FreeCamDH11	FreeCamDH11	5169	3	142	99.06	8	5010.1
2	12	19	2021	MD	FxC21	FreeCamDH12	FreeCamDH12	5132	5	144	99.06	3	5178.2
2	13	1	2021	MD	FxC21	FreeCamDH13	FreeCamDH13	5044	7	143	111.76	7	5386.7
2	14	13	2021	MD	FxC21	FreeCamDH14	FreeCamDH14	5101	4	142	104.14	8	4734.4
2	15	17	2021	MD	FxC21	FreeCamDH15	FreeCamDH15	5121	7	143	93.98	3	4283.8
2	16	27	2021	MD	FxC21	FreeCamDH16	FreeCamDH16	5174	5	145	99.06	0	4646.9
2	17	23	2021	MD	FxC21	FreeCamDH17	FreeCamDH17	5154	3	145	109.22	5	5380
2	18	30	2021	MD	FxC21	FreeCamDH18	FreeCamDH18	5188	6	145	86.36	0	4707.5
2	19	3	2021	MD	FxC21	FreeCamDH19	FreeCamDH19	5051	7	142	101.6	7	4546.1
2	20	28	2021	MD	FxC21	FreeCamDH20	FreeCamDH20	5178	6	142	109.22	4	5023.5
2	21	4	2021	MD	FxC21	FreeCamDH21	FreeCamDH21	5056	5	142	101.6	4	4889

Supplemental Table S4.3. Continued

2	22	6	2021	MD	FxC21	FreeCamDH22	FreeCamDH22	5070	4	143	93.98	2	5198.4
2	23	18	2021	MD	FxC21	FreeCamDH23	FreeCamDH23	5129	4	141	99.06	1	4687.3
2	24	2	2021	MD	FxC21	FreeCamDH24	FreeCamDH24	5047	7	140	101.6	5	4707.5
2	25	12	2021	MD	FxC21	FreeCamDH25	FreeCamDH25	5099	6	143	111.76	1	3523.9
2	26	18	2021	MD	FxC21	FreeCamDH26	FreeCamDH26	5127	7	142	93.98	1	4667.1
2	27	29	2021	MD	FxC21	FreeCamDH27	FreeCamDH27	5184	7	143	101.6	0	5232
2	28	31	2021	MD	FxC21	FreeCamDH28	FreeCamDH28	5193	6	144	99.06	0	5635.5
2	29	31	2021	MD	FxC21	FreeCamDH29	FreeCamDH29	5191	7	144	99.06	0	4761.3
2	30	32	2021	MD	FxC21	FreeCamDH30	FreeCamDH30	5197	6	139	86.36	0	5272.4
2	31	8	2021	MD	FxC21	FreeCamDH31	FreeCamDH31	5078	5	142	109.22	2	5292.5
2	32	13	2021	MD	FxC21	FreeCamDH32	FreeCamDH32	5104	5	143	101.6	7	4499
2	33	26	2021	MD	FxC21	FreeCamDH33	FreeCamDH33	5168	5	142	101.6	3	5534.6
2	34	36	2021	MD	FxC21	FreeCamDH34	FreeCamDH34	5217	6	143	106.68	3	4875.6
2	35	8	2021	MD	FxC21	FreeCamDH35	FreeCamDH35	5077	7	144	106.68	6	5043.7
2	36	2	2021	MD	FxC21	FreeCamDH36	FreeCamDH36	5048	7	142	106.68	6	5366.5
2	37	34	2021	MD	FxC21	FreeCamDH37	FreeCamDH37	5210	5	140	104.14	7	5050.4
2	38	28	2021	MD	FxC21	FreeCamDH38	FreeCamDH38	5177	6	143	104.14	5	4344.3
2	39	17	2021	MD	FxC21	FreeCamDH39	FreeCamDH39	5122	7	142	99.06	1	5440.5
2	40	15	2021	MD	FxC21	FreeCamDH40	FreeCamDH40	5112	8	143	104.14	0	5258.9
2	41	3	2021	MD	FxC21	FreeCamDH41	FreeCamDH41	5053	5	140	99.06	4	5016.8
2	42	35	2021	MD	FxC21	FreeCamDH42	FreeCamDH42	5215	7	142	99.06	8	5393.4

2	43	32	2021	MD	FxC21	FreeCamDH43	FreeCamDH43	5198	6	141	106.68	6	4741.1
2	44	9	2021	MD	FxC21	FreeCamDH44	FreeCamDH44	5081	6	139	104.14	4	4505.7
2	45	22	2021	MD	-	SD05W018	SD05W018	5148	8	142	101.6	5	4189.6
2	46	7	2021	MD	FxC21	FreeCamDH46	FreeCamDH45	5071	8	144	101.6	4	4949.6
2	47	27	2021	MD	FxC21	FreeCamDH47	FreeCamDH46	5175	7	146	111.76	2	4747.8
2	48	16	2021	MD	FxC21	FreeCamDH48	FreeCamDH47	5120	3	142	99.06	8	4909.2
2	49	13	2021	MD	FxC21	FreeCamDH49	FreeCamDH48	5103	8	143	93.98	3	5057.2
2	50	7	2021	MD	FxC21	FreeCamDH50	FreeCamDH49	5074	5	140	96.52	7	5312.7
2	51	32	2021	MD	FxC21	FreeCamDH51	FreeCamDH50	5200	5	142	101.6	2	4929.4
2	52	17	2021	MD	FxC21	FreeCamDH52	FreeCamDH51	5124	4	144	96.52	3	4815.1
2	53	4	2021	MD	FxC21	FreeCamDH53	FreeCamDH52	5058	4	143	101.6	1	4250.2
2	54	20	2021	MD	FxC21	FreeCamDH54	FreeCamDH53	5138	6	143	99.06	3	5211.8
2	55	8	2021	MD	FxC21	FreeCamDH55	FreeCamDH54	5076	4	142	99.06	8	3974.4
2	56	22	2021	MD	FxC21	FreeCamDH56	FreeCamDH55	5146	5	144	101.6	8	4176.2
2	57	6	2021	MD	FxC21	FreeCamDH57	FreeCamDH56	5069	5	142	111.76	8	5346.3
2	58	6	2021	MD	FxC21	FreeCamDH58	FreeCamDH57	5066	4	143	106.68	8	3940.8
2	59	10	2021	MD	FxC21	FreeCamDH59	FreeCamDH58	5090	6	143	93.98	0	5467.4
2	60	16	2021	MD	FxC21	FreeCamDH60	FreeCamDH59	5116	4	142	101.6	8	4082
2	61	20	2021	MD	FxC21	FreeCamDH61	FreeCamDH60	5137	6	143	104.14	7	4451.9
2	62	1	2021	MD	FxC21	FreeCamDH62	FreeCamDH61	5041	5	140	101.6	2	5205.1
2	63	33	2021	MD	FxC21	FreeCamDH63	FreeCamDH62	5205	6	144	93.98	0	4398.1
2	64	23	2021	MD	FxC21	FreeCamDH64	FreeCamDH63	5155	4	145	96.52	7	5319.4
2	65	13	2021	MD	FxC21	FreeCamDH65	FreeCamDH64	5105	6	142	104.14	4	5285.8

Supplemental Table S4.3. Continued

2	66	7	2021	MD	FxC21	FreeCamDH66	FreeCamDH65	5073	6	141	106.68	8	5380
2	67	13	2021	MD	FxC21	FreeCamDH67	FreeCamDH66	5102	7	144	96.52	0	5460.7
2	68	35	2021	MD	FxC21	FreeCamDH68	FreeCamDH67	5213	6	142	101.6	1	4808.3
2	69	4	2021	MD	FxC21	FreeCamDH69	FreeCamDH68	5059	6	142	96.52	0	5608.6
2	70	19	2021	MD	FxC21	FreeCamDH70	FreeCamDH69	5131	5	144	104.14	7	4808.3
2	71	3	2021	MD	FxC21	FreeCamDH71	FreeCamDH70	5052	6	141	88.9	3	5198.4
2	72	14	2021	MD	FxC21	FreeCamDH72	FreeCamDH71	5107	6	142	96.52	7	5460.7
2	73	25	2021	MD	FxC21	FreeCamDH73	FreeCamDH72	5162	7	142	101.6	1	4512.4
2	74	9	2021	MD	FxC21	FreeCamDH74	FreeCamDH73	5085	7	144	99.06	1	5077.3
2	75	26	2021	MD	FxC21	FreeCamDH75	FreeCamDH74	5170	4	143	96.52	6	5696
2	76	30	2021	MD	FxC21	FreeCamDH76	FreeCamDH75	5186	4	146	96.52	2	4794.9
2	77	12	2021	MD	FxC21	FreeCamDH77	FreeCamDH76	5100	7	142	93.98	7	5285.8
2	78	29	2021	MD	FxC21	FreeCamDH78	FreeCamDH77	5181	6	145	96.52	1	5729.7
2	79	20	2021	MD	FxC21	FreeCamDH79	FreeCamDH78	5140	3	144	99.06	0	5171.5
2	80	4	2021	MD	FxC21	FreeCamDH80	FreeCamDH79	5057	6	141	96.52	8	4808.3
2	81	24	2021	MD	FxC21	FreeCamDH81	FreeCamDH80	5156	4	146	104.14	4	4949.6
2	82	7	2021	MD	FxC21	FreeCamDH82	FreeCamDH81	5075	4	141	101.6	8	5232
2	83	26	2021	MD	FxC21	FreeCamDH83	FreeCamDH82	5167	3	144	93.98	8	4485.5
2	84	24	2021	MD	FxC21	FreeCamDH84	FreeCamDH83	5159	5	143	99.06	0	5575
2	85	20	2021	MD	FxC21	FreeCamDH85	FreeCamDH84	5139	4	142	104.14	7	4956.3
2	86	5	2021	MD	FxC21	FreeCamDH86	FreeCamDH85	5062	5	143	99.06	7	4788.2

Supplemental Table S4.3. Continued

2	87	22	2021	MD	FxC21	FreeCamDH87	FreeCamDH86	5147	7	142	96.52	8	4909.2
2	88	12	2021	MD	FxC21	FreeCamDH88	FreeCamDH87	5098	5	140	104.14	2	4828.5
2	89	24	2021	MD	FxC21	FreeCamDH89	FreeCamDH88	5157	7	141	101.6	2	4041.7
2	89	24	2021	MD	FxC21	FreeCamDH89	FreeCamDH88	5157	7	141	101.6	2	4041.7
2	90	2	2021	MD	FxC21	FreeCamDH90	FreeCamDH89	5050	8	143	93.98	2	5722.9
2	91	15	2021	MD	FxC21	FreeCamDH91	FreeCamDH90	5113	5	145	93.98	0	5722.9
2	92	1	2021	MD	FxC21	FreeCamDH92	FreeCamDH91	5042	6	144	93.98	1	5258.9
2	93	18	2021	MD	FxC21	FreeCamDH93	FreeCamDH92	5130	6	143	88.9	0	6039
2	94	31	2021	MD	FxC21	FreeCamDH94	FreeCamDH93	5194	6	142	96.52	7	4983.2
2	95	8	2021	MD	FxC21	FreeCamDH95	FreeCamDH94	5080	5	143	96.52	3	4936.1
2	96	16	2021	MD	FxC21	FreeCamDH96	FreeCamDH95	5119	5	143	96.52	6	4633.5
2	97	21	2021	MD	FxC21	FreeCamDH97	FreeCamDH96	5145	3	145	104.14	1	4660.4
2	98	31	2021	MD	FxC21	FreeCamDH98	FreeCamDH97	5192	5	143	101.6	1	4714.2
2	99	10	2021	MD	FxC21	FreeCamDH99	FreeCamDH98	5087	4	141	99.06	0	5178.2
2	100	27	2021	MD	FxC21	FreeCamDH100	FreeCamDH99	5171	7	142	104.14	0	4384.7
2	101	10	2021	MD	FxC21	FreeCamDH101	FreeCamDH100	5089	7	142	104.14	0	5864.2
2	102	2	2021	MD	FxC21	FreeCamDH102	FreeCamDH101	5049	4	141	96.52	8	4586.4
2	103	26	2021	MD	FxC21	FreeCamDH103	FreeCamDH102	5166	3	145	101.6	2	5104.2
2	104	23	2021	MD	FxC21	FreeCamDH104	FreeCamDH103	5153	7	143	96.52	8	5057.2
2	105	32	2021	MD	FxC21	FreeCamDH105	FreeCamDH104	5196	4	140	101.6	1	5548.1
2	106	21	2021	MD	FxC21	FreeCamDH106	FreeCamDH105	5141	7	143	104.14	4	4707.5

Supplemental Table S4.3. Continued

2	107	35	2021	MD	FxC21	FreeCamDH107	FreeCamDH106	5211	6	143	99.06	0	5702.8
2	108	34	2021	MD	FxC21	FreeCamDH108	FreeCamDH107	5207	4	144	109.22	2	5440.5
2	109	36	2021	MD	FxC21	FreeCamDH109	FreeCamDH108	5220	7	143	99.06	3	5339.6
2	110	17	2021	MD	FxC21	FreeCamDH110	FreeCamDH109	5123	4	145	91.44	7	4754.5
2	111	23	2021	MD	FxC21	FreeCamDH111	FreeCamDH110	5152	8	141	99.06	0	5124.4
2	112	22	2021	MD	FxC21	FreeCamDH112	FreeCamDH111	5149	4	143	88.9	8	4525.9
2	113	25	2021	MD	FxC21	FreeCamDH113	FreeCamDH112	5161	5	145	104.14	7	4599.9
2	114	30	2021	MD	FxC21	FreeCamDH114	FreeCamDH113	5187	5	144	96.52	0	5655.7
2	115	6	2021	MD	FxC21	FreeCamDH115	FreeCamDH114	5067	6	143	96.52	8	5447.2
2	116	11	2021	MD	FxC21	FreeCamDH116	FreeCamDH115	5091	8	144	99.06	0	5191.7
2	117	27	2021	MD	FxC21	FreeCamDH117	FreeCamDH116	5172	4	140	96.52	0	4552.8
2	118	21	2021	MD	FxC21	FreeCamDH118	FreeCamDH117	5142	7	142	99.06	5	5063.9
2	119	4	2021	MD	FxC21	FreeCamDH119	FreeCamDH118	5060	7	143	99.06	0	5050.4
2	120	14	2021	MD	FxC21	FreeCamDH120	FreeCamDH119	5106	4	140	96.52	2	4431.7
2	121	14	2021	MD	FxC21	FreeCamDH121	FreeCamDH120	5110	4	144	109.22	5	4808.3
2	122	5	2021	MD	FxC21	FreeCamDH122	FreeCamDH121	5061	6	143	101.6	3	4640.2
2	123	25	2021	MD	FxC21	FreeCamDH123	FreeCamDH122	5164	4	144	99.06	3	5447.2
2	124	19	2021	MD	FxC21	FreeCamDH124	FreeCamDH123	5135	5	142	99.06	1	4149.3
2	125	14	2021	MD	FxC21	FreeCamDH125	FreeCamDH124	5108	6	141	86.36	8	5440.5
2	126	36	2021	MD	FxC21	FreeCamDH126	FreeCamDH125	5218	5	145	106.68	7	5137.9
2	127	31	2021	MD	FxC21	FreeCamDH127	FreeCamDH126	5195	7	140	93.98	2	5830.5

Supplemental Table S4.3. Continued

2	128	9	2021	MD	FxC21	FreeCamDH128	FreeCamDH127	5084	4	143	106.68	6	4095.5
2	129	29	2021	MD	FxC21	FreeCamDH129	FreeCamDH128	5183	7	142	93.98	0	5420.3
2	130	17	2021	MD	FxC21	FreeCamDH130	FreeCamDH129	5125	6	143	104.14	6	5057.2
2	131	15	2021	MD	FxC21	FreeCamDH131	FreeCamDH130	5111	5	143	81.28	3	4922.7
2	132	33	2021	MD	FxC21	FreeCamDH132	FreeCamDH131	5201	3	141	93.98	0	5252.2
2	133	23	2021	MD	FxC21	FreeCamDH133	FreeCamDH132	5151	4	143	99.06	3	5306
2	134	18	2021	MD	FxC21	FreeCamDH134	FreeCamDH133	5128	5	143	101.6	7	4976.5
2	135	5	2021	MD	FxC21	FreeCamDH135	FreeCamDH134	5065	5	142	99.06	0	4788.2
2	136	24	2021	MD	FxC21	FreeCamDH136	FreeCamDH135	5160	7	142	101.6	3	4633.5
2	137	18	2021	MD	FxC21	FreeCamDH137	FreeCamDH136	5126	7	142	104.14	0	5016.8
2	138	1	2021	MD	FxC21	FreeCamDH138	FreeCamDH137	5043	4	143	78.74	4	5817.1
2	139	28	2021	MD	FxC21	FreeCamDH139	FreeCamDH138	5176	6	145	99.06	8	4055.1
2	140	12	2021	MD	FxC21	FreeCamDH140	FreeCamDH139	5097	5	139	91.44	5	4532.6
2	141	35	2021	MD	FxC21	FreeCamDH141	FreeCamDH140	5214	7	141	99.06	0	5191.7
2	142	20	2021	MD	FxC21	FreeCamDH142	FreeCamDH141	5136	4	140	96.52	6	4586.4
2	143	29	2021	MD	FxC21	FreeCamDH143	FreeCamDH142	5182	7	145	99.06	0	5198.4
2	144	36	2021	MD	FxC21	FreeCamDH144	FreeCamDH143	5219	6	144	106.68	0	4727.6
2	145	25	2021	MD	FxC21	FreeCamDH145	FreeCamDH144	5163	5	142	88.9	0	5063.9
2	146	33	2021	MD	FxC21	FreeCamDH146	FreeCamDH145	5203	6	141	91.44	0	5891.1
2	147	11	2021	MD	FxC21	FreeCamDH147	FreeCamDH146	5095	6	142	104.14	7	4794.9
2	148	33	2021	MD	FxC21	FreeCamDH148	FreeCamDH147	5202	7	140	93.98	0	5480.8

Supplemental Table S4.3. Continued

2	149	12	2021	MD	FxC21	FreeCamDH149	FreeCamDH148	5096	6	142	106.68	8	4425
2	150	19	2021	MD	FxC21	FreeCamDH150	FreeCamDH149	5133	4	145	96.52	8	4169.5
2	151	2	2021	MD	FxC21	FreeCamDH151	FreeCamDH150	5046	6	142	101.6	6	5010.1
2	152	5	2021	MD	FxC21	FreeCamDH152	FreeCamDH151	5063	6	145	109.22	8	4613.3
2	153	10	2021	MD	FxC21	FreeCamDH153	FreeCamDH152	5088	5	143	93.98	0	5198.4
2	154	11	2021	MD	FxC21	FreeCamDH154	FreeCamDH153	5094	6	143	106.68	6	5359.8
2	155	9	2021	MD	FxC21	FreeCamDH155	FreeCamDH154	5082	6	141	96.52	5	4061.9
2	156	27	2021	MD	FxC21	FreeCamDH156	FreeCamDH155	5173	5	142	93.98	4	5077.3
2	157	15	2021	MD	FxC21	FreeCamDH157	FreeCamDH156	5115	5	141	93.98	2	4707.5
2	158	15	2021	MD	FxC21	FreeCamDH158	FreeCamDH157	5114	7	144	96.52	3	5232
2	159	19	2021	MD	FxC21	FreeCamDH159	FreeCamDH158	5134	4	140	99.06	0	5534.6
2	160	22	2021	MD	FxC21	FreeCamDH160	FreeCamDH159	5150	3	144	101.6	4	5070.6
2	161	7	2021	MD	FxC21	FreeCamDH161	FreeCamDH160	5072	7	143	101.6	0	5588.4
2	162	34	2021	MD	FxC21	FreeCamDH162	FreeCamDH161	5209	5	143	99.06	1	5453.9
2	163	21	2021	MD	FxC21	FreeCamDH163	FreeCamDH162	5143	6	143	104.14	7	4976.5
2	164	6	2021	MD	FxC21	FreeCamDH164	FreeCamDH163	5068	6	141	99.06	8	5319.4
2	165	28	2021	MD	FxC21	FreeCamDH165	FreeCamDH164	5180	6	143	99.06	3	5265.6
2	166	30	2021	MD	FxC21	FreeCamDH166	FreeCamDH165	5189	7	142	101.6	0	6940.2
2	167	24	2021	MD	FxC21	FreeCamDH167	FreeCamDH166	5158	5	142	101.6	4	4512.4
2	168	9	2021	MD	FxC21	FreeCamDH168	FreeCamDH167	5083	7	141	96.52	7	5346.3
2	169	10	2021	MD	FxC21	FreeCamDH169	FreeCamDH168	5086	5	145	96.52	3	5077.3

Supplemental Table S4.3. Continued

2	170	1	2021	MD	FxC21	FreeCamDH170	FreeCamDH169	5045	7	143	106.68	8	5050.4
2	171	35	2021	MD	FxC21	FreeCamDH171	FreeCamDH170	5212	7	142	93.98	0	5084.1
2	172	14	2021	MD	FxC21	FreeCamDH172	FreeCamDH171	5109	3	140	101.6	8	5245.5
2	173	8	2021	MD	FxC21	FreeCamDH173	FreeCamDH172	5079	7	143	99.06	0	5299.3
2	174	34	2021	MD	FxC21	FreeCamDH174	FreeCamDH173	5208	7	143	93.98	0	3604.6
2	175	5	2021	MD	FxC21	FreeCamDH175	FreeCamDH174	5064	8	143	96.52	1	4398.1
2	176	30	2021	MD	-	Camelot	Camelot	5190	4	143	106.68	0	5440.5
2	177	36	2021	MD	-	Freeman	Freeman	5216	7	140	101.6	6	4653.7
2	178	28	2021	MD	-	TAM107	TAM107	5179	5	141	101.6	0	4337.6
2	179	3	2021	MD	-	NI15713	NI15713	5055	4	145	96.52	7	5164.8
2	180	3	2021	MD	-	Pete	Pete	5054	2	137	91.44	0	3907.2

Abbreviations: REP, replication; LOC, location; EXP, experiment; AE, anther extrusion; AD, days to anthesis; PH, plant height; LODG, lodging; GYLD, grain yield.