INFLUENCE OF PREHARVEST HERBICIDE APPLICATIONS ON DESICCATION, YIELD AND COLOR RETENTION OF BLACK BEANS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Crop and Soil Sciences – Master of Science

2015

ABSTRACT

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The retention of the black color in canned black beans is viewed as a key attribute in finished product quality and is very important for consumer acceptance. Changes in production practices and black bean varieties may influence canned black bean quality. A field trial was conducted near Richville, Michigan in 2013 and 2014 to evaluate the effects of preharvest herbicide treatments on desiccation, yield, and black bean quality and color. The black bean varieties Zorro, Eclipse, and Zenith were planted on two different dates in each of two years. Three preharvest herbicide treatments, paraquat, glyphosate, and saflufenacil, were applied at two different application timings. Differences in black bean desiccation were greatest 3 DAT, with paraquat and saflufenacil showing the quickest desiccation. By 7 DAT, desiccation for most preharvest treatments was over 95%. Early applications of saflufenacil in the first planting had the greatest impact on yield for both years when compared with the nontreated control. Black bean color was lighter when glyphosate was applied early to Zenith and Zorro as assessed by a panel of over 20 evaluators. Lightness (L*) measurements also indicate lighter black bean color after canning with early applications of glyphosate. Eclipse had the lightest L* measurements while Zenith had the darkest, regardless of planting date or application timing. Overall, preharvest herbicides applied at the early application timing reduced black bean yield, with the largest reduction observed from applications of saflufenacil. The greatest loss of black color in canned beans was observed when glyphosate was applied at the early application timing; however, preharvest treatments applied at the standard timing very rarely impacted bean color.

Dedicated to my parents, Greg and Marie Goffnett

ACKNOWLEDGMENTS

I would like to thank Dr. Christy Sprague for giving me the opportunity to be part of the weed science program and for serving as my major professor. Her guidance, patience, and support have been essential to my education and personal development. I would also like to thank Dr. Karen Cichy and Dr. Christina DiFonzo for serving on my guidance committee and for always being available to provide valuable insight.

It would have been difficult to conduct this research without the help of Gary Powell and Erin Hill. It was a pleasure to work with them and I greatly appreciate their assistance, advice, and sense of humor. Also, thank you to Paul Horny and Dennis Fleischman at the Saginaw Valley Research and Extension Center for their hospitality and for maintaining my research plots. I would like to thank Dr. James Kelly, Evan Wright, Norm Blakely, Scott Shaw, and Fernando Mendoza for their assistance with my research. Thanks to The Michigan Bean Commission, Michigan Department of Agriculture and Rural Development, and Project Greeen for funding this research.

Thank you to my fellow graduate students: Amanda Harden, David Powell, Jon Kohrt, Victoria Ackroyd, and Kelsey Rogers for all your help and support. Additionally, thank you to the undergraduate workers: Megan Tomlin, Canton Brissette, Cody Tyrrell, Chris Bauer, Chelsey Bonthuis, Matt Rau, Kalvin Canfield, R.J. Lee, Taylor Truckey, Kelly White, Connor Hubbard, Morgan Cnudde, and Mike Schulze. I would also like to thank Dr. James Kells and Dr. Thomas Nikolai for allowing me to serve as their teaching assistant. Finally, I would like to extend a special thank you to my family and friends for their love and support.

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CHAPTER 1

LITERATURE REVIEW

Introduction

Dry bean (*Phaseolus vulgaris* L.) is an annual, short-season, leguminous crop that serves as an important human food staple (Kelly and Cichy 2013; Robertson and Frazier 1978). As a relatively inexpensive source of protein, dry beans are mainly consumed in parts of the world where meat is not readily available. In addition to being the leading source of vegetable protein, dry beans are also rich in vitamins, minerals, soluble dietary fiber, and antioxidants (USDA-ERS 2012). Dry beans are divided into several market classes based on specific characteristics. Pinto beans (42%), navy beans (17%), black beans (11%), great northern beans (5%), and garbanzo beans (5%) are the most commonly grown market classes in the U.S. The U.S. is one of the top dry bean producing countries in the world, following Brazil and Mexico, with over 20% of U.S. dry bean production exported (Akibode and Maredia 2012). In 2013, over 548,000 hectares in the U.S. were planted to dry beans, generating a nationwide farm gate value of $976 million (USDA-NASS 2014).

North Dakota (38%) and Michigan (14%) together contribute one-half of the total national dry bean production (USDA-ERS 2012). Michigan is the nation's top producer of black, cranberry, and small red beans, and is second in production of navy and kidney beans. Black beans and navy beans are the largest commercial dry bean classes in Michigan, with 45% and 34% of the market share, respectively (USDA-NASS 2014). The production value of Michigan's 2013 black bean crop was $61 million, contributing considerably to the state's agricultural economy.

Dry bean architecture advancements

Dry beans are classified into four growth types referred to as Types I, II, III, and IV. Type I beans are characterized by having determinate growth and Types II, III, and IV have indeterminate growth (Kelly and Cichy 2013; Kelly 2001, 2010; Urwin et al. 1996). Beans with determinate growth halt vegetative extension at flowering, whereas beans with indeterminate growth continue vegetative growth during flowering. Type I beans are bush-like with pod placement on upright branches. Type II (upright) beans produce a narrow plant, with short vines, and an upright growth habit similar to that of soybean [*Glycine max* (L.) Merr.]. Type III beans have semi-prostrate or long-prostrate vines. Type IV beans have a climbing growth habit and are rarely grown in the United States, but are commonly grown in East Africa and Latin America (Kelly and Cichy 2013).

Breeding efforts began in the 1970s to develop Type II varieties suitable for direct harvest (Adams 1995). Prior to the development of Type II (upright) beans, the United States predominantly grew Type III beans with semi-prostrate vines, which required a multiple-step harvest system (Kelly and Cichy 2013; Schwartz et al. 2004). In this harvest system, beans were pulled at physiological maturity with green tissue still remaining. This process was done using either a knife-puller (blade puller) or a rod-puller (Pickett puller) specially mounted to a tractor (Kelly and Cichy 2013; Schwartz et al. 2004; Robertson and Frazier 1978). Pulled bean plants from several rows were consolidated into windrows. This reduced the amount of soil and stones that ultimately went through the thresher. Beans would dry in the windrow, often for multiple days, before threshing occurred (Kelly and Cichy 2013; Robertson and Frazier 1978). Threshing was usually performed using a pickup header on a self-propelled combine.

In the Midwest, erratic precipitation forced growers to pull and windrow beans during the early morning when dew was still on the plant, allowed them to dry during the day, and threshed them later in the afternoon (Kelly and Cichy 2013). This harvest system was very labor intensive and costly because each operation required specialized equipment and a separate pass across the field, thus preventing growers from expanding in acreage (Kelly and Cichy 2013; Schwartz et al. 2004; Robertson and Frazier 1978). Yield losses commonly occurred during the drying phase of this harvest system, when plants were left on the soil surface and exposed to fluctuating environmental conditions and insect feeding (Boudreaux and Griffin 2011; Cook 2004; Wilson and Smith 2002).

Upright growth habit and short vine development made Type II beans suitable for direct harvest. The direct harvest system allowed beans to be cut, gathered, and threshed in one operation, thus eliminating the need for specialized equipment and reducing yield loss that occurred during the drying period (Schwartz et al. 2004; Harrigan et al. 1992; Robertson and Fraizer 1978). Combines with conventional-type soybean headers were initially used in direct harvest systems, but harvest losses of 20 to 40% were commonly observed (Schwartz et al. 2004). Several equipment advances reduced the amount of harvest loss with the direct cut system. Improvements to the header included using a flexible, floating cutter bar (sickle bar) with a narrow pitch, and lifting guards to raise the pods above the cutter bar (Schwartz et al. 2004; Harrigan et al. 1992). Another major development was replacing the traditional header reel with an air reel, which injects air in front of the cutter bar to lift and move plants. Advances in harvest equipment reduced the amount of harvest loss from 20 to 40%, down to 3 to 7% (Schwartz et al. 2004). The direct harvest system is also suitable for upright beans grown in narrow rows (40 to 55 cm) at higher plant populations. Narrow-row production results in pods forming higher on the plant (reduces harvest loss) and increases plant competitiveness with weeds (Schwartz et al. 2004; Harrigan et al. 1992; Robertson and Fraizer 1978).

The traditional weed control method of inter-row cultivation in dry beans is not practiced in direct harvest systems (Schwartz 2004; Robertson and Frazier 1978). Inter-row cultivation is an additional pass across the field, creates soil mounds, and brings rocks to the soil surface (Schwartz 2004; Robertson and Frazier 1978). Instead, growers rely on preemergence (PRE) and postemergence (POST) herbicides for weed control (Schwartz et al. 2004; Blackshaw et al. 2000; Robertson and Frazier 1978). Additionally, planting Type II beans in narrow rows and at higher plant populations improves weed control (Holmes and Sprague 2013). The direct harvest system requires a relatively flat surface free from soil mounds, rocks, and green plant tissue. Type II bean harvest is delayed when leaves, green stems, and green pods are still present on the plant at physiological maturity (Boudreaux and Griffin 2011; Wilson and Smith 2002). Weeds and green crop tissue can cause harvest difficulties by hanging up on the cutter bar and reel of the header, plugging the combine, increasing moisture and raising foreign material count. The resulting reduction in quality can lower market price (Schwartz et al. 2004; Wilson and Smith 2002; Robertson and Frazier 1978).

Preharvest herbicides

To facilitate direct harvest, preharvest herbicide (also referred to as desiccant or harvest-aid) applications are primarily used to desiccate weeds remaining in the field and to accelerate and promote uniform dry bean maturation (Kelly and Cichy 2013; Boudreaux and Griffin 2011; Griffin et al. 2010; Schwartz et al. 2004; Wilson and Smith 2002). Herbicides used in preharvest applications generally differ in their speed of activity and effectiveness, and few herbicides are registered for preharvest use in dry beans (Griffin et al. 2010). The herbicides most commonly used in Michigan are paraquat, glyphosate, flumioxazin, and saflufenacil (Sprague 2015).

Paraquat is a fast-acting, non-selective herbicide that results in injury symptoms appearing within 1 to 2 hours after application in full sunlight (Shaner 2014; Griffin et al. 2010). Complete foliar necrosis is usually observed within 1 to 3 d (Griffin et al. 2010). This contact herbicide disrupts plant cell membranes by diverting electrons in photosystem I and leads to the formation of free radicals such as superoxide, hydroxyl, and peroxide (Shaner 2014). The paraquat molecule is readily regenerated from re-oxidization of free radicals by atmospheric oxygen, making paraquat very active at low doses (Fuerst et al. 1985). Injury symptoms from paraquat include water soaked appearance on leaves followed by necrosis and desiccation of leaves and stems (Fishel 2005). Paraquat is labeled for applications to mature beans, when at least 80% of the pods are yellow. The total application rate may not exceed 0.56 kg ha^{-1} (Anonymous 2013). There must be at least 7 d between the paraquat application and dry bean harvest. Paraquat is classified as a restricted use pesticide (RUP) because of high acute toxicity and it requires a state pesticide applicator certification for purchase and use.

Glyphosate is a non-selective, systemic herbicide that inhibits the 5-enolpyruvyl-shikimate-3-phosphate (EPSP) enzyme (Shaner 2014; Griffin et al. 2010). The inhibition of EPSP synthase leads to reductions in aromatic amino acids, which are vital for protein synthesis and plant growth (Shaner 2014). Plants exposed to glyphosate exhibit stunting, leaf malformation, foliar chlorosis, and necrosis. Plant death occurs in 4 to 7 d for highly susceptible species and 10 to 20 d for less susceptible species (Griffin et al. 2010; Ellis and Griffin 2002). Glyphosate as a preharvest treatment is labeled for use on dry beans when seed moisture is 30%

or less and rates cannot exceed 0.84 kg ae ha^{-1} (Anonymous 2012). A preharvest interval (PHI) of 7 d is required. If applied too early, glyphosate can translocate into the seed, potentially resulting in dry bean export rejections from illegal residue limits (above 2.0 ppm) (McNaughton et al. 2015).

Flumioxazin is a cell membrane disruptor herbicide that inhibits protoporphyrinogen oxidase (PPO) (Shaner 2014). The inhibition of PPO results in the accumulation of protoporphyrinogen IX, which oxidizes to protoporphyrin IX and reacts to generate singlet oxygen. Lipid peroxidation is then initiated and disruption of the cell membrane occurs. Residual activity of flumioxazin may injure certain crops, so rotational restrictions are necessary (Anonymous 2010). The maximum application rate of flumioxazin as a preharvest herbicide for dry beans is 0.05 kg ha^{-1}, with a 5 d PHI.

Saflufenacil was commercially released in 2010 as a selective herbicide and a desiccant (Grossman et al. 2010). Similar to flumioxazin, saflufenacil is classified as a PPO inhibitor, and desiccates plants within 1 to 3 d (Anonymous 2014). Saflufenacil must be applied at dry bean maturity (80% of pods are yellow) with a maximum application rate of 0.05 kg ha^{-1}. A 2 d PHI is required. The maximum residue limit for saflufenacil is 0.01 ppm (McNaughton et al. 2015).

Preharvest herbicides are used on several crops including dry bean, soybean, wheat, pea, and cotton (*Gossypium hirsutum* L.) (Griffin et al. 2010; Baig et al. 2003; Yenish and Young 2000). Soltani et al. (2013) conducted a study over three years and across 11 locations in Canada (Ontario, Manitoba, and Alberta) to evaluate the effect of diquat (0.55 kg ai ha^{-1}), carfentrazone-ethyl (0.28 kg ai ha^{-1}), glufosinate ammonium (0.45 kg ae ha^{-1}), flumioxazin (0.71 kg ai ha^{-1}), and saflufenacil (0.50 kg ai ha^{-1}) on the desiccation of dry beans (cranberry, great northern, and white bean). Preharvest herbicides were applied alone or mixed with glyphosate, at either 0.45 or 0.90 kg ae ha^{-1}, when 80% of the pods were yellow. Desiccation of the leaves, stem, and pods was visually evaluated 4 and 8 d after application (DAA). When glyphosate was applied with another herbicide, desiccation improved by only 1% (at both 4 and 8 DAA), compared with herbicides applied alone. Desiccation by glyphosate was similar to untreated dry beans 8 DAA, indicating the slowest desiccation with applications of glyphosate.

Glyphosate and saflufenacil were also evaluated in Canada (Ontario, Manitoba, and Alberta) on kidney, navy, cranberry, pinto, and great northern beans (McNaughton et al. 2015). The effects of glyphosate (0.90 kg ae ha^{-1}) and saflufenacil (0.50 kg ai ha^{-1}), applied alone or together on dry beans were evaluated. Applications were made when 0, 25, 50, 75, and 100% of pods were yellow and desiccation was visually evaluated for the leaf, stem, and pods 4, 8, 12, and 16 DAA. Desiccation results reported by McNaughton et al. (2015) indicated quicker desiccation across all application timings with saflufenacil compared with glyphosate and there was no advantage from mixing saflufenacil with glyphosate. These findings agreed with Soltani et al. (2013), concluding a slow desiccation from glyphosate and no improvement in desiccation from tank-mixing glyphosate with other herbicides.

Wilson and Smith (2002) examined the effect of pulling and windrowing, compared with preharvest treatments of glufosinate (0.44 kg ai ha^{-1}), glyphosate (0.84 kg ae ha^{-1}), and paraquat (0.56 kg ai ha^{-1}) on the desiccation of determinate light red kidney beans and indeterminate great northern beans grown in Nebraska. Preharvest treatments were applied when 5, 36, and 77% of the pods were yellow in 1998 and when 7, 61, and 85% of the pods were yellow in 1999. Desiccation was determined by measuring plant, pod, and seed moisture at 0, 5, 10, and 15 d after treatment (DAT). When preharvest treatments were applied at the latest timing (77 or 85% of pods were yellow) and evaluated 5 DAT, no difference in desiccation were observed in either year. Paraquat and glufosinate applications resulted in 8 to 17% greater desiccation than glyphosate at 5 DAT. By 10 DAT, no difference was observed among treatments, except for glyphosate applied when 5% of the pods were yellow in 1998. However, the standard application timing for preharvest herbicides is at physiological maturity of dry beans, when 80% of the pods are yellow; applications prior to this stage are not legal.

Applying preharvest herbicides prior to crop physiological maturity can have a negative impact on dry seed quality (McNaughton et al. 2015; Baig et al. 2003; Wilson and Smith 2002; Bennett and Shaw 2000; Yenish and Young 2000; Ratnayake and Shaw 1992). Seedling emergence for indeterminate and determinate varieties of field pea (*Pisum sativaum*) was reduced when preharvest applications of glyphosate (0.9 kg ae ha^{-1}) were applied at high seed moisture contents (SMC) (>40%). Preharvest applications of glyphosate applied at a low SMC, <30%, had no impact on seedling emergence (Baig et al. 2003). Glyphosate applied at early maturity stages in soft white spring wheat (*Triticum aestivum* L.) had a negative impact on seed weight and germination (Yenish and Young 2000). Yenish and Young (2000) examined the effects of preharvest applications of glyphosate (0.62 or 0.84 kg ae ha^{-1}) applied to soft white spring wheat at the milk, soft dough, and hard dough stages (Zadoks' scale 70 to 79, 85, and 87, respectively). Only glyphosate applications made at the milk stage had a negative impact on seed weight and yield. They observed a 19 to 73% reduction in seed weight and a 2 to 46% reduction in germination compared with the untreated.

Preharvest herbicide applications can also impact the dry seed quality of soybean (Bennett and Shaw 2000; Ratnayake and Shaw 1992). Ratnayake and Shaw (1992) evaluated the influence of AC 263,222 (imidazolinone family) (0.22 kg ai ha^{-1}), glufosinate (0.84 kg ai ha^{-1}), glyphosate (0.56 kg ae ha^{-1}), and paraquat (0.84 kg ai ha^{-1}) on soybean seed quality, applied at R5 (“beginning seed”, when seed is 3 mm long and the pod is located at one of the four uppermost nodes on main stem), R6 (“full seed”, when the pod contains green seed that fills the pod capacity at one of four uppermost nodes on main stem), R7 (“beginning maturity”, when plants are shedding leaves and contain one pod with mature color), and R8 (“full maturity”, when 95% of pods reach mature color and grain moisture is about 35%) soybean growth stages. Soybean seed germination was not reduced by preharvest herbicide treatments applied at R8, but was reduced by 6% when glyphosate was applied at the R7 growth stage. Both glyphosate and AC 263,222 reduced germination at the R5 and R6 soybean growth stages, by 8 and 15% at R5 and 15 and 35% at R6, respectively, when compared with the untreated under weed-free conditions. Preharvest herbicide treatments applied at R7 and R8 growth stage had no effect on soybean 100-seed weight, but paraquat and glufosinate both reduced seed weight when applied at R5 and R6 soybean growth stage. Glufosinate reduced 100-seed weight by 25 and 27%, while paraquat reduced seed weight by 34 and 23% at the R5 and R6 growth stages, respectively.

To evaluate the effects of two preharvest herbicide treatments on the seed characteristics of conventional and glyphosate-resistant soybean, a study was conducted at two locations in Mississippi (Bennett and Shaw 2000). Preharvest treatments of glyphosate (1.1 kg ai ha^{-1}) and paraquat (0.3 kg ai ha^{-1}), both mixed with sodium chlorate (6.7 kg ai ha^{-1}) were applied to conventional and glyphosate-resistant Group IV soybean varieties at the R5, R6, R7, and R8 growth stages. When combined over preharvest treatments and locations, seed weight of both the transgenic and conventional variety was reduced by 11 and 17%, respectively, when preharvest treatments were applied at the R5 growth stage. Seed weight was also reduced after applications made at the R6 growth stage for the transgenic variety, but no reduction was observed for the conventional variety. Seed germination was reduced in both varieties when preharvest herbicide applications were applied early (R5 to R7 growth stage), but not at the R8 growth stage. Soybean germination reductions ranged from 13 to 53% for the conventional variety and 19 to 46% for the transgenic variety.

Seed germination of soybean was impacted more by early applications of preharvest herbicides than studies conducted with light red kidney and great northern beans (Wilson and Smith 2002; Bennett and Shaw 2000). Light red kidney and great northern beans were grown in Nebraska over two years to determine the influence of glufosinate (0.44 kg ae ha^{-1}), glyphosate (0.84 kg ae ha^{-1}), and paraquat (0.56 kg ai ha^{-1}) on dry bean seed quality. Preharvest treatments were applied at 5, 36, and 77% of pods yellow in the first year, and 7, 61, and 85% of pods yellow in the second year. Dry bean seed germination was only reduced by 5% when glufosinate (first year) or paraquat (second year) were applied when 5 or 7% of pods were yellow. In one year, an average of 20, 10, and 6% reduction in dry bean seed weight was observed for preharvest applications made at the 5, 36, and 77% yellow pod stage, respectively. In the next year, dry bean seed weight was only reduced with applications of glufosinate and paraquat (11 and 13%, respectively) when 7% of the pods were yellow.

In addition to dry seed quality reductions, yield reductions can also occur when preharvest herbicide applications are made prior to physiological maturity of a crop (McNaughton et al. 2015; Soltani et al. 2013; Boudreaux and Griffin 2011; Wilson and Smith 2002; Bennett and Shaw 2000; Yenish and Young 2000; Ratnayake and Shaw 1992). Yield reductions of 20 to 77% were reported when glyphosate (0.62 or 0.84 kg ae ha^{-1}) was applied to soft white spring wheat at the milk stage, while no yield reduction was reported at the soft dough or hard dough stage (Yenish and Young 2000). Preharvest applications of glyphosate plus sodium chlorate or paraquat plus sodium chlorate on conventional and transgenic (glyphosate-tolerant) soybean grown in Mississippi resulted in lower yields prior to the R7 soybean growth stage (Bennett and Shaw 2000). A 21% yield reduction in the transgenic variety was reported when preharvest herbicides were applied at the R5 soybean growth stage. Soybean yields were lower in the conventional variety by 21 and 19%, when preharvest herbicides were applied at the R5 and R6 soybean growth stage, respectively.

Under weed-free conditions, 85 to 97% and 42 to 81% lower soybean yields were reported from one year to another, when paraquat (0.84 kg ai ha^{-1}), glyphosate (0.56 kg ai ha^{-1}), glufosinate (0.84 kg ai ha^{-1}), or AC 263,222 (imidazolinone family) (0.22 kg ai ha^{-1}) was applied at the R5 soybean growth stage (Ratnayake and Shaw 1992). At the R6 soybean growth stage, preharvest applications of paraquat and glufosinate lowered yields from 27 to 36% for both years, while glyphosate and AC 263,222 had no effect. Soybean yield was not reduced by applications of any preharvest herbicide at R7 or R8 soybean growth stages. Soybean yield was reduced by 15% when preharvest applications of paraquat (0.28 kg ai ha^{-1}), paraquat plus carfentrazone (0.014 kg ai ha^{-1}), and sodium chlorate (6.72 kg ai ha^{-1}) were made at 60% seed moisture (about R6 growth stage), compared with the control (Boudreaux and Griffin 2011). Boudreaux and Griffin (2011) also noted that preharvest applications made to soybean with ≤50% seed moisture (about R7 growth stage) did not affect yield and plants were harvested 14 to 15 d sooner than control plants.

Wilson and Smith (2002) observed similar results when glyphosate, glufosinate, and paraquat applications were made prior to maturity of light red kidney and great northern beans (80% yellow pods or R8 growth stage). Applications of paraquat and glufosinate made at 5 to 7% yellow pods resulted in a yield reduction of 19 to 63%, depending on the year, while applications made at 77 to 85% yellow pods did not reduce yield. Glyphosate caused slight yield reductions (24%) when 5 to 7% of pods were yellow in the first year, but did not cause yield reductions in the second year. Differences in the effect of glyphosate on yield between the years could have resulted from subtle variations in environmental conditions prolonging the plant response to glyphosate.

Black bean varieties

Black bean consumption, commonly as a canned product, has increased in the past few years. T-39 (the industry standard), was a traditional black bean variety that reached maturity in 95 to 100 d (Osorno et al. 2009). The intermediate height of T-39 was not conducive to direct harvest; therefore, breeding efforts began to improve black bean varieties for use in direct harvest systems.

The black bean variety Jaguar, released in 2000, was suitable for narrow-row production and direct harvest in Michigan (Kelly 2000). Jaguar had higher canned appearance ratings than T-39 (4.5 vs. 2.8, respectively, using a seven point scale) and produced seed with a dull, instead of shiny, seed coat (Kelly et al. 2009). A dull black seed coat is highly desired by the canning industry due to its ability to quickly absorb more water than beans with a shiny seed coat, thus increasing the number of cans produced per unit of raw material (Wright and Kelly 2011; Bushey et al. 2000; Osorno et al. 2009).

Further varietal improvements focused on disease resistance, agronomic traits, appearance and color of beans following canning (Kelly et al. 2009, 2014; Kelly 2001). White mold tolerance and higher yields were observed with the black bean variety Eclipse, released in 2004 (Osorno et al. 2009). Eclipse reaches maturity in about 95 d (Kelly et al. 2014) and is primarily grown in North Dakota and Minnesota (80% of black bean acres) (G. Varner, personal communication, Michigan Bean Commission 2015). Data collected from over 25 environments indicated that Eclipse yields exceeded other commercial black bean varieties available at that time, including Jaguar and T-39, by 10 to 12% (average of 2632 kg ha^{-1}) (Osorno et al. 2009). Black bean yield and disease tolerance increased even further with the release of Zorro (100 d maturity) in 2008 (Kelly et al. 2009). Zorro was the first black bean variety with moderate resistance to common bacterial blight, and was grown on an estimated 90% of Michigan black bean acres in 2014 (G. Varner, personal communication, Michigan Bean Commission 2015). Zorro yields, averaged over 5 years (2004-2008) and 36 locations, surpassed yields of other commercial control varieties, including T-39 (13%), Jaguar (8%), and Eclipse (10%) (Kelly et al. 2009).

The newest variety released in Michigan was Zenith (100 d maturity) in 2014, which is expected to replace most of the Zorro market (Kelly et al. 2014). In studies conducted over 4 years and 32 locations, Zenith exceeded yields of: T-39 (12%), Jaguar (10%), Eclipse (11%), and

Zorro (6%). Superior canning quality and color were also observed with Zenith. Zenith ranked the highest in visual appearance, receiving 4.5 out of 5, while Zorro received 4.0 and Eclipse received 3.6. Visual color assessment after canning also resulted in Zenith scoring the highest (4.6), followed by Zorro (3.5), T-39 (3.3), and Eclipse (2.3). Lightness of the canned commercial samples was measured using a colorimeter (L* scale). Zenith also had the darkest color (13.1), followed by Zorro (15.8), T-39 (16.2), Jaguar (17.5), and Eclipse (18.1). Canning quality and color retention of black bean varieties are considered key attributes of the finished product by consumers and processors (Kelly et al. 2009, 2014; Posa-Macalincag et al. 2002).

Canning quality of black beans

Consumers and dry bean processors prefer a canned black bean product with intact beans, desirable texture (55-65 kg force) (Hosfield and Uebersax 1980), and a dark black color (Posa-Macalincag et al. 2002). Texture is a measure of the firmness or softness perceived by consumers when chewing the processed bean (Ghaderi et al. 1984). A sheer press is used to measure texture by determining the amount of constant force (kg) required to crush a 100 g sample of processed beans (Hosfield and Uebersax 1980). To decrease costs, bean processors strongly prefer varieties with uniform and rapid water uptake, which make indicators like hydration coefficient and washed-drained coefficient of interest to the canning industry (Hosfield 1991). The hydration coefficient indicates bean hydration prior to thermal processing and is determined by the ratio of the soaked bean weight (g) to the fresh bean weight (g); 1.8 is considered optimum (Hosfield and Uebersax 1980). The washed-drained coefficient is a method used to evaluate water entrainment by examining the ratio of the washed-drained bean weight (g) to the soaked bean weight (g); the ideal range is 1.4 to 1.6 (Hosfield and Uebersax 1980). The rating of canned appearance indicates the suitability of the variety for commercial canning (Hosfield et al. 1984). Canned black bean appearance is determined by a subjective rating using a hedonic scale that takes into consideration splits, clumps, brine starchiness, and brine consistency. Canned black bean surface color is also evaluated using subjective ratings, ranking the bean color from lightest to darkest.

In addition to subjective color evaluations, surface color is commonly measured using either a spectrophotometer or a colorimeter (Mendoza et al. 2015; Anonymous 2000). A spectrophotometer measures the spectral reflectance by breaking up light into several bands across the visible spectrum and displaying reflectance data at specific wavelengths (Anonymous 2000). While the spectrophotometer is ideal for analyzing spectral emission of an illumination source, the colorimeter is best used for measuring color based on what the human eye would see. Colorimeters use edge band filters to break up light into three bands (red, green, and blue), or color components, and fits them to a mathematical model of human color vision (Anonymous 2000; Hosfield and Uebersax 1991). Colorimeter measurements are displayed as three values that act as coordinates in a three-dimensional color space. These three values are commonly represented using the L*a*b* scale; where L* represents lightness and darkness (100 is perfect white, 50 is gray, and 0 is perfect black), a* measures redness and greenness (positive values are redness, 0 is gray, and negative values are greenness), and b* measures yellowness and blueness (positive values are yellowness, 0 is gray, and negative values are blueness) (Mendoza et al. 2015; Anonymous 2000; Sangwine 2000; Hosfield and Uebersax 1991).

Although both the spectrophotometer and the colorimeter provide accurate (to the 0.1 unit) and repeatable measurements, a major disadvantage is that the sample must be fairly homogenous and several samples may need to be measured for accurate representation (Mendoza et al. 2015; Hosfield and Uebersax 1991). A newer alternative to using the spectrophotometer or the colorimeter is computerized image analysis techniques, also called machine vision or computer vision (Mendoza et al. 2015). The machine vision system uses standard fluorescent illuminants, a color digital camera, and image processing software to acquire a full field view of the sample, or specific segmented regions of interest, and calculate standard color parameters. A color calibration and camera characterization of the machine vision system is completed to ensure an accurate color measurement that is equivalent to the colorimeter. The machine vision system can also be used for other quality assessment parameters, such as texture, in addition to color evaluation.

The desirable dark color of the black bean seed coat is attributed to the accumulation of anthocyanins (mainly delpinidin 3-glucoside, petunidin 3-glucoside, and malvidin 3-glucoside), which are water-soluble pigments that are responsible for most of the red, purple, and blue colors exhibited by plant tissue (Cheynier 2012; Takeoka et al. 1997). These water-soluble phenolic (or polyphenolic) compounds can be readily leached during soaking and thermal processing (Bushey et al. 2000; Takeoka et al. 1997). Excessive leaching of anthocyanins results in a faded brown or grey appearance of the canned product; this negatively impacts consumer acceptability (Cichy et al. 2014; Wright and Kelly 2011; Marles et al. 2010). Processing methods, such as soaking, boiling, and steaming can affect phenolic compounds and antioxidant activity associated with seed coat color in black beans (Xu and Chang 2008). Xu and Chang (2008) observed less of a loss in the total phenolic content (TPC), antioxidant activity (measured with DPPH radical scavenging and oxygen radical absorbing capacity), and solid mass with steaming compared with boiling. Steaming resulted in a 70 to 75% loss of TPC, a 28 to 36% and 17 to 46% loss in antioxidant activity (DPPH radical scavenging and oxygen radical absorbing capacity, respectively), and a 0.97 to 3% loss in solid mass compared with unprocessed beans. From the boiling process, TPC was reduced by 75 to 77%, antioxidant activity loss was 18 to 44% and 30 to 88% (DPPH radical scavenging and oxygen radical absorbing capacity, respectively), and solid mass was reduced by 8 to 10% compared with unprocessed beans. Although greater loss was seen with black beans exposed to the boiling process, substantial amounts of antioxidants were still found in the beans.

Factors outside of the canning process may also influence black bean color after canning. While variety is the main determinant of dry bean quality and color, environmental influences and the interaction of variety with environment also have an impact on canning quality (Marles et al. 2010; Balasubramanian et al. 1999; Shellie and Hosfield 1991; Ghaderi et al. 1984; Hosfield et al. 1984). A dry bean study conducted at three Michigan locations in 1980 reported a significant variety by site (location) interaction with navy beans for the quality traits seed weight, dry seed color, hydration coefficient, processed seed moisture, clumps, and splits (Ghaderi et al. 1984). This study also examined phenotypic correlation coefficients for quality traits and found very low associations, indicating quality traits were independent of each other. Hosfield et al. (1984) examined the seasonal and genotypic effects on the quality of 25 black bean varieties grown at the same location over 3 yrs. The variety-by-year interaction was significant for all quality traits measured (washed-drained weight, texture, and cooked bean color), and year or the year-by-variety interaction had a larger effect on black bean quality traits than genotype.

Black bean quality traits were influenced by variety, growing location, and year at 13 Saskatchewan locations over two years (Balasubramanian et al. 1999). Balasubramanian et al. (1999) reported a significant variety-by-location-by-year interaction for black bean quality traits of seed weight, dry seed color, hydration coefficient, appearance, washed-drained weight, and processed color. There were significant differences among black bean varieties in seed weight, appearance, texture, and processed color. Herbicides may have an effect on soluble hydroxyphenolic compound levels and anthocyanin content in plants, and thus impact seed color (Hoagland 1980; Duke et al. 1979). Duke et al. (1979) found that root-fed glyphosate reduced the level of soluble hydroxyphenolic compounds in soybean seedlings grown in both light and dark environments. Hoagland (1980) reported a substantial reduction in anthocyanin content when glyphosate was applied to soybean seedlings. A 44% anthocyanin reduction per gram of fresh weight of soybean compared with the control and a 49% anthocyanin reduction per soybean hypocotyl compared with the control were reported.

Factors such as environmental growing conditions, variety, and possibly preharvest herbicide selection and application timing may have an effect on black bean quality. Approximately 45.5 million kg of canned black beans are produced in the United States (USDA-ERS 2012) and a negative influence on quality and color will be damaging to the canning industry. Limited research exists on the effect of preharvest herbicide, application timing, and black bean variety on canning quality and color retention.

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CHAPTER 2

INFLUENCE OF PREHARVEST HERBICIDE APPLICATIONS ON DESICCATION, YIELD AND COLOR RETENTION OF BLACK BEANS

Abstract

The retention of the black color in canned black beans is viewed as a key attribute in finished product quality and is very important for consumer acceptance. Changes in production practices and black bean varieties may influence canned dry bean quality. A field trial was conducted at the Saginaw Valley Research and Extension Center near Richville, Michigan, in 2013 and 2014 to evaluate the effects of preharvest herbicide treatments on desiccation, yield, and black bean quality and color. The Type II black bean varieties Zorro, Eclipse, and Zenith were planted on two different dates in each of two years. Three preharvest herbicide treatments, paraquat, glyphosate, and saflufenacil, were applied at two different application timings, early (pods = 50% yellow) and standard (pods = 80% yellow), for each planting date. A nontreated control was established for each variety. Differences in black bean desiccation were greatest 3 DAT, with paraquat and saflufenacil showing the quickest desiccation at the early application timing. By 7 DAT, desiccation for most preharvest treatments was over 95%. Early applications of saflufenacil in the first planting had the greatest impact on yield for both years when compared with the nontreated controls. This may be due to the quicker speed of activity halting dry bean development. At the standard application timing, saflufenacil did not differ from other treatments for both years of the first planting. Black bean color was lighter when glyphosate was applied early to Zenith and Zorro as assessed by a panel of over 20 evaluators. Lightness (L*) measurements also indicate lighter black bean color after canning with early applications of glyphosate. Eclipse had the lightest L* measurements while Zenith had the darkest, regardless of planting date or application timing. Overall preharvest herbicides applied at the early timing reduced black bean yield, with the largest reduction observed from applications of saflufenacil. The greatest loss of black color in canned beans was observed when glyphosate was applied at the early application timing, however preharvest treatments applied at the standard timing had very little impact on bean color. Therefore, growers should be conscious of appropriate application timing and preharvest herbicide selection.

Nomenclature: Paraquat; glyphosate; saflufenacil; dry bean, *Phaseolus vulgaris* L. Eclipse, Zorro, Zenith.

Key Words: Dry edible bean, *Phaseolus vulgaris* L., harvest aid, desiccant, color retention.

Introduction

Michigan is the nation's top black bean (*Phaseolus vulgaris* L.) producing state, with 48,500 ha planted in 2014 (USDA-NASS 2015). Historically, most black bean varieties grown in the U.S. were semi-prostrate vines (Type III), which required the use of a multiple-step harvest system, consisting of specialized equipment to pull, windrow, and thresh beans once they were dry (Kelly and Cichy 2013; Schwartz et al. 2004). This harvest system was labor intensive and costly because each operation required specialized equipment and a separate pass across the field, preventing growers from increasing in acreage (Kelly and Cichy 2013; Schwartz et al. 2004; Robertson and Frazier 1978). Yield losses were common during the drying phase of this harvest system, because plants were left on the soil surface and exposed to fluctuating environmental conditions and insect feeding (Boudreaux and Griffin 2011; Cook 2004; Wilson and Smith 2002).

Breeding began in the 1970s to develop Type II dry beans varieties with an upright growth habit suitable for direct harvest (Adams 1995). In 2005, Michigan growers started using direct harvest methods and by 2010, an estimated 50 to 55% of Michigan's black bean acres were direct harvested (G. Varner, personal communication, Michigan Bean Commission 2015). Over 90% of Michigan's black bean acres were direct harvested in 2014. The direct harvest system allows beans to be cut, gathered, and threshed in one operation using a combine, thus eliminating the need for specialized equipment and reducing yield losses that occurred in windrows (Schwartz et al. 2004; Harrigan et al. 1992; Robertson and Fraizer 1978). However, harvest may be delayed in the direct harvest system if leaves, green stems, and green pods are still present on the plant at physiological maturity, or if weeds are present in the field (Boudreaux and Griffin 2011; Wilson and Smith 2002). Weeds and green crop tissue cause harvest difficulties by slowing the efficiency of the header cutter bar and reel, and by plugging the combine. They also increase the seed moisture and foreign material in the harvested crop, resulting in a lower market price (Schwartz et al. 2004; Wilson and Smith 2002; Robertson and Frazier 1978). Direct harvest is facilitated when preharvest herbicide applications (also referred to as desiccants or harvest-aids) are used to desiccate weeds that may remain in the field, and to accelerate and promote uniform dry bean maturation (Kelly and Cichy 2013; Boudreaux and Griffin 2011; Griffin et al. 2010; Schwartz et al. 2004; Wilson and Smith 2002).

Preharvest herbicides have been shown to differ in effectiveness and speed of activity (Griffin et al. 2010; Wilson and Smith 2002; Ratnayake and Shaw 1992). Fast-acting herbicides, like paraquat, can result in complete foliar necrosis within 3 d (Griffin et al. 2010). Slower-acting herbicides, like glyphosate, may take up to 15 d before plant death occurs (Griffin et al. 2010; Ellis and Griffin 2002). Soltani et al. (2013) reported that complete desiccation of cranberry, great northern, and white beans was about 4 d slower with preharvest applications of glyphosate compared with diquat, carfentrazone-ethyl, glufosinate ammonium, flumioxazin, and saflufenacil. Applying preharvest herbicides prior to crop physiological maturity can have a negative impact on seed weight, seed germination, and yield (McNaughton et al. 2015; Wilson and Smith 2002). McNaughton et al. (2015) reported that seed weight was reduced by up to 16% when kidney, navy, cranberry, pinto, and great northern beans were treated with a preharvest application of saflufenacil plus glyphosate when pods were still green. Wilson and Smith (2002) reported that early applications (5 to 7% pods yellow) of paraquat and glufosinate reduced dry bean seed germination by 2 and 5%, respectively. However, there was no reduction from later applications when 36 to 61% of pods were yellow. Dry bean yield was reduced up to 40% when preharvest herbicides were applied when only 0 and 5% of the pods were yellow, but yield was not affected when applications were delayed until 80% of the pods were yellow (McNaughton et al. 2015; Wilson and Smith 2002).

Consumers and bean processors prefer a canned black bean product with intact beans, desirable texture, and retention of a dark, black color (Posa-Macalincag et al. 2002; Hosfield and Uebersax 1980). The desirable dark color of the black bean seed coat is attributed to the accumulation of anthocyanins (mainly delpinidin 3-glucoside, petunidin 3-glucoside, and malvidin 3-glucoside), which are water-soluble pigments responsible for most of the red, purple, and blue colors exhibited by plant tissue (Cheynier 2012; Takeoka et al. 1997). These water-soluble phenolic (or polyphenolic) compounds are readily leached during soaking and thermal processing (Bushey et al. 2000; Takeoka et al. 1997). Processing methods, such as soaking, boiling, and steaming, can affect phenolic compounds and antioxidant activity associated with seed coat color in black beans (Xu and Chang 2008).

Other factors, such as variety and environmental influences, also affect black bean color after canning (Marles et al. 2010; Balasubramanian et al. 1999; Hosfield et al. 1984). Hosfield et al. (1984) examined seasonal and genotypic effects on the quality of 25 black bean varieties grown at the same location over 3 yrs. The variety-by-year interaction was significant for all quality traits measured (washed-drained weight, texture, and cooked bean color) and had a larger effect on black bean quality traits than variety alone. Marles et al. (2010) found genotype to be the greatest determinate in seed color expression of black beans grown in different environments. However, growing conditions may also influence genes in the flavonoid pathway, which can affect the color of canned black beans (Marles et al. 2010).

Since canning quality and color of black beans are key components in consumer acceptability, a product that appears faded brown or grey is undesirable (Cichy et al. 2014; Wright and Kelly 2011). While, variety and processing both affect the color of canned black beans, little is known about the effect of preharvest herbicide treatments on the quality and color of canned black beans. Therefore, the objective of this research was to evaluate the effect of preharvest herbicide treatments on the desiccation, yield, seed weight, seed germination, and canning quality and color of three Type II black bean varieties under different environmental conditions.

Materials and Methods

Field research was conducted at the Michigan State University Saginaw Valley Research and Extension Center near Richville, Michigan (43°24′ N, 83°41′ W) in 2013 and 2014. The soil type was a Tappan-Londo loam (fine-loamy, mixed, active, calcareous, mesic Typic Endoaquolls and fine-loamy, mixed, mesic, Aeric Glossaqualfs) with a pH of 7.7 and organic matter of 4.1% in 2013 and pH of 7.6 with 3% organic matter in 2014. The experiment was setup as a split-split-split randomized complete block design with four replications. The main plot factor consisted of two planting dates, the first planting date occurred at the beginning of a typical dry bean growing season in Michigan, and second was two to three weeks later. The sub-plot factors were black bean variety, preharvest herbicide application timings, and preharvest herbicide treatments. Each plot measured 3 m wide by 10.7 m in length.

Prior to planting dry beans, fields were fall moldboard plowed and soil finished twice in the spring. Three Type II (upright indeterminate vine) black bean varieties Eclipse (Treasure Valley Seed Co., Homedale, ID), Zorro (Michigan Crop Improvement Association, Lansing, MI), and Zenith (Michigan Crop Improvement Association, Lansing, MI) were planted on June 13 and June 26 in 2013 and June 5 and June 27 in 2014. Average days to maturity are 96 d, 100 d, and 100 d for Eclipse, Zorro, and Zenith, respectively (Kelly et al. 2014). Each variety was planted at a population of 262,000 seeds ha^{-1} in 76 cm rows. Plots were kept weed-free with preplant incorporated (PPI) and postemergence (POST) herbicide applications. *S*-metolachlor (Dual II Magnum, Syngenta Corporation, Wilmington, DE) at 1.07 kg ai ha^{-1} and EPTC (Eptam, Gowan Company, Yuma, AZ) at 2.5 kg ai ha^{-1} were applied immediately prior to the last soil finish operation, approximately two weeks prior to planting. Additionally, 252 kg ha^{-1} of 17-8-15 (N-P-K) fertilizer containing 1.5% manganese and zinc was broadcast prior to the last incorporation. A POST application of 35 g ai ha^{-1} of imazamox (Raptor, BASF Corporation, Research Triangle Park, NC), 0.70 kg ai ha^{-1} of bentazon (Basagran, BASF Corportation, Research Triangle Park, NC), 0.28 kg ai ha^{-1} of fomesafen (Reflex, Syngenta Corporation, Wilmington, DE), 1% v v^{-1} of crop oil concentrate (Herbimax, Loveland Products Inc., Loveland, CO), and 2% w w^{-1} of ammonium sulfate (Actamaster, Loveland Products Inc., Loveland, CO) was made when dry beans were at the V2 to V3 growth stage.

Preharvest herbicide applications were made at two different timings for each planting date: early (50% of dry bean pods were yellow) and standard (80% of pods were yellow). The early application timing simulated conditions of uneven dry bean maturity typically observed in Michigan fields and to help determine the effects of early preharvest herbicide applications on dry bean desiccation, yield, and bean quality. Maturity was assessed for each black bean variety at the time of the preharvest herbicide applications. The three preharvest herbicide treatments examined were: 1) paraquat (Gramoxone® SL, Syngenta Corporation, Wilmington, DE) at 0.56 kg ai ha^{-1} applied with 0.25% v v^{-1} non-ionic surfactant (Activator 90, Loveland Products Inc., Loveland, CO), 2) glyphosate (Roundup PowerMax®, Monsanto Company, St. Louis, MO) at 0.84 kg ae ha^{-1} with 2% w w^{-1} ammonium sulfate, and 3) saflufenacil (Sharpen®, BASF Corporation, Research Triangle Park, NC) at 0.05 kg ai ha^{-1} plus 1% v v^{-1} methylated seed oil (Super Spread, Wilbur-Ellis Company, Fresno, CA) and 2% w w^{-1} ammonium sulfate. These treatments were compared to a nontreated control for each variety. Treatments were applied using a tractor-mounted compressed-air sprayer calibrated to deliver 177 L ha^{-1} at 193 kPa using AirMix 11003 nozzles (Greenleaf Technologies, Covington, LA).

Temperature and precipitation data were obtained throughout the growing season (June-September) from Michigan State University's Enviro-weather online database (MSU Enviro-weather 2015) (Table B2.1, B2.2, and B2.3). The environmental station was located within one mile of the research plot.

Black bean desiccation, yield and seed quality

Black bean desiccation was assessed 3, 7, and 14 d after the preharvest herbicide treatments (DAT) on a scale of 0-99%, with 0 indicating all green tissue and 99 indicating complete plant desiccation (no green tissue) for the early-planted black beans. Desiccation was assessed only 3 and 7 DAT for the later-planted black beans. The two center rows of each plot were direct harvested for yield with a small plot combine (Hege 140, Hege Company, Waldenburg, Germany, F.R.) after the last evaluation. Black bean yield was adjusted to 18% moisture. Harvest dates were September 17 for the early-planted and October 2 for the later-planted black beans in 2013. In 2014, harvest dates were September 9 for the early-planted and October 8 for the later-planted black beans. Following harvest, 100-seed weight was recorded and 25 seeds were placed on filter paper in petri dishes, soaked with 6 ml of de-ionized water, and held in a germination chamber at 20 C for 4 d to test seed germination. The remainder of the seed samples were examined to ensure they were free of malformed or damaged seed. Cleaned samples were placed in an air-circulating humidity chamber two weeks before canning to equilibrate moisture.

Dry seed color was measured using the color parameters of L*, a*, and b*. The L* component measures lightness from 0 (black) to 100 (white), while a* measures red to green (positive values = redness, 0 = gray, and negative values = greenness), and b* measures yellow to blue (positive values = yellowness, 0 = gray, and negative values = blueness) chromatic components. In 2013, dry seed color was measured using a Hunter Labscan XE colorimeter (Hunter Associate Laboratory, Inc., Reston, VA). In 2014, L*, a*, and b* values were measured using a computerized image analysis technique (also called computer vision or machine vision) described by Mendoza et al. (2015). The machine vision used standard fluorescent illuminants, a color digital camera, and image processing software to acquire a full field view or segmented regions of interest and a standard color measurement, as obtained with a colorimeter. The machine vision system was calibrated using a color target-based characterization using color samples with known measurements to ensure an accurate measurement of color.

Canned bean quality and color

Black bean samples were canned using a small-scale protocol (Hosfield et al. 1984) that simulates large-scale industry canning. Cleaned 100 g bean samples from each plot were cold soaked in a solution of distilled water with 0.03% calcium chloride for 1 hr. After soaking, samples were transferred to tinplate cans (300 x 407, 198 to 227 g capacity) and weighed to obtain the soaked bean weight. After weighing, cans were filled with brine at 100 C, containing 1.5% sucrose, 1.2% sodium chloride, 0.03% calcium chloride, and distilled water. Filled cans were sent through an exhaust tunnel to remove air bubbles from the brine, sealed, and processed in a retort (National Board No. 813, Loveless Manufacturing, Tulsa, OK) for 45 min at 116 C and cooled to 38 C with cold water. Cans were stored for at least 4 weeks prior to opening, for equilibration.

Canned samples were opened and assessed for appearance (integrity and uniformity) and color by a trained panel of evaluators, using a 1 to 5 scale. Appearance ratings were defined as: 1 = unacceptable (severely split seeds, not holding together); 2 = poor (badly split seeds but holding together); 3 = average (60 to 69% of seeds intact); 4 = very good (70 to 89% of seeds intact); and 5 = excellent (at least 90% of seeds intact). Ratings for color were defined as: 1 = very light brown (50% color variation); 2 = slight dark brown or light gray (11 to 49% color variation); 3 = average brown or black (5 to 10% color variation); 4 = dark brown or medium black (less than 5% color variation); and 5 = very dark (100% color uniformity). The panel consisted of students, technicians, researchers, and professors working with dry beans. There were 22 evaluators for canned bean samples from the 2013 field season and 25 evaluators for samples from the 2014 field season.

Following the panel evaluation, samples were washed with water to remove the brine, drained on standard number 8 (2.36 mm) sieves, and air dried. The weight of each washed-drained sample was then recorded. From the recorded weights, hydration coefficient and washed-drained coefficient were calculated.

Hydration coefficient = *soaked bean weight (g) / fresh weight (g) equivalent to 100 g solids* [1]

Washed-drained coefficient = *washed-drained weight (g) / soaked bean weight (g)* [2]

Canned black bean color was evaluated by measuring the L*, a*, and b* color parameters of the washed-drained sample using a colorimeter in 2013 and the machine vision system in 2014, as previously described. Canned black bean texture was measured by placing 100 g of the washed-drained bean sample in a shear-compression cell and applying pressure using a Kramer Shear press to compress the sample to the point of catastrophic failure (Food Technology Corp., Rockville, MD). Texture was recorded as kg-force per 100 g sample.

Statistical analysis

Data were analyzed using ANOVA and PROC MIXED in SAS 9.3 (SAS Institute Inc., Cary, NC). Normality of residuals and homogeneity of variances were evaluated using the UNIVARIATE procedure in SAS. There were significant interactions between planting dates and years, so data are presented separately. Data were combined over preharvest application timings when no significant interactions existed. The main effects of black bean variety and preharvest herbicide were examined for interactions and presented separately when significant interactions occurred. Data means were separated using Fisher's protected LSD at the $\alpha \leq 0.05$ level of significance. The CORR procedure in SAS was used to determine Pearson's correlation coefficient to assess linear correlations between seed and canned bean quality and color measurements.

Results and Discussion

Black bean desiccation

The greatest difference in black bean desiccation occurred when preharvest herbicide treatments were applied at the early application timing (pods = 50% yellow) compared with the standard application timing (pods = 80% yellow), therefore desiccation results are presented separately for the two application timings within each planting date.

First planting date. There was a significant variety-by-preharvest treatment interaction for black bean desiccation 3 and 7 DAT when the preharvest herbicides were applied at the early application timing in 2013 (Table 2.1). The three black bean varieties, Eclipse, Zorro, and Zenith, differed in maturation for the early application timing. The nontreated controls of Eclipse, Zorro, and Zenith reached 88, 70, and 63% maturity 3 DAT, respectively. At this time, there was not a significant difference in desiccation between nontreated and glyphosate-treated plots for each variety. However, the preharvest treatments of paraquat and saflufenacil provided significantly greater desiccation than the nontreated controls and glyphosate, with paraquat being more effective than saflufenacil for all varieties. Desiccation of Eclipse, Zorro, and Zenith was 98, 94, and 96% with paraquat and 93, 84, and 79% with saflufenacil, respectively. By 7 DAT, desiccation of all three black bean varieties was greater than 95% with glyphosate, paraquat, and saflufenacil (Table 2.1). However, the effectiveness of glyphosate was similar to paraquat and saflufenacil only when applied to Eclipse. Black bean desiccation with glyphosate was slightly lower than paraquat and saflufenacil when glyphosate was applied to Zorro and Zenith. This may be due to the initial differences in black bean maturation between the three varieties.

Desiccation 3 DAT differed by the main effects of variety and preharvest treatment for the early application timing in 2014 (Table 2.2). Combined over all preharvest treatments, initial desiccation of Eclipse (78%) was > Zorro or Zenith (68%). All preharvest herbicide treatments provided greater black bean desiccation than the nontreated control at 3 DAT. However, desiccation was greater for paraquat (79%) and saflufenacil (77%) compared with glyphosate (68%). There was a significant variety-by-preharvest treatment interaction at 7 DAT black bean desiccation results (Table 2.1). All preharvest herbicide treatments provided 95% or greater desiccation, with the exception of glyphosate application to Zenith (83%). By 14 DAT, desiccation with all herbicides for the three varieties was greater than the natural maturity of the nontreated controls (data not shown).

Black bean desiccation at the standard application timing (80% yellow pods) was also different between the two years for the first planting. There was a variety-by-preharvest treatment interaction for the 3 and 7 DAT desiccation results in 2013 (Table 2.1). Black bean desiccation 3 DAT was greater than 90% for all preharvest herbicide treatments and the nontreated controls. All herbicide treatments with the exception of glyphosate applied to Zorro provided greater desiccation than the maturation for nontreated controls of Zorro and Zenith. Glyphosate, paraquat, and saflufenacil, applied at the standard application timing did not improve desiccation of Eclipse over the nontreated control (98%), since this variety had already reached complete maturity by 3 DAT. By 7 DAT, black bean desiccation was greater than 95% for all varieties.

There was not a significant variety-by-preharvest treatment interaction for the 3 and 7 DAT desiccation evaluations in 2014 when treatments were applied at the standard application timing, therefore main effects are presented (Table 2.2). Averaged over all preharvest treatments, the desiccation among the varieties was Eclipse (98%) > Zenith (96%) > Zorro (95%). Similar to the early application timing, paraquat and saflufenacil provided the most desiccation 3 DAT. However, by 7 DAT all treatments including glyphosate provided greater desiccation than the maturation of the nontreated control.

Second planting date. The main effects of black bean variety and preharvest treatment are presented for black bean desiccation 3 DAT for the early application timing in 2013 (Table 2.2). Black bean maturation and desiccation were faster for Eclipse (88%) and Zenith (82%) compared with Zorro (70%) in 2013. Combined across all black bean varieties, desiccation from early applications of saflufenacil (95%) was greater than paraquat (79%) and glyphosate (77%) 3 DAT. However, these herbicides still provided quicker desiccation than the nontreated control (69%). At 7 DAT, there was a significant variety and preharvest treatment interaction (Table 2.1). Similar to the first planting, no differences were observed in desiccation between preharvest herbicides applied to Eclipse, while applications of paraquat and saflufenacil resulted in > 95% desiccation, with the exception of paraquat applied to Zorro (86%) which took until 14 DAT to reach 98% (data not shown). Slower maturation and desiccation 7 DAT for the nontreated and early timings of glyphosate may be the result of overall lower temperatures and higher precipitation shortly after application for the second planting, compared with the first planting in 2013 (Table B2.2).

There was a black bean variety-by-preharvest treatment interaction for desiccation 3 and 7 DAT for the early application timing in 2014 (Table 2.1). Similar to what occurred in the first planting in 2013, saflufenacil and paraquat provided the quickest overall desiccation 3 DAT. However, desiccation was slightly lower for paraquat (86%) applied to Zorro compared with saflufenacil (91%). By 7 DAT, all herbicides provided 98% or greater desiccation.

Black bean desiccation at the standard application timing (pods = 80% yellow) also differed between years for the second planting. The main effects of black bean variety and preharvest treatment for desiccation 3 DAT are presented for each year (Table 2.2). Averaged over all preharvest treatments, desiccation was greatest for Eclipse (94%) and Zenith (93%) when compared with Zorro (87%) in 2013. However, in 2014 desiccation was quicker for Eclipse than Zorro or Zenith, indicating this variety was further along in maturity at the time of the preharvest herbicide applications. Differences in the speed of activity among the three herbicides showed that the greatest desiccation was from saflufenacil 3 DAT in 2013. In 2014, all preharvest herbicides provided similar levels of desiccation (95%). Desiccation was 95% or greater with all preharvest herbicide applications by 7 DAT in both years (Table 2.1 and 2.2).

Overall results among the black bean varieties showed that desiccation tended to be greater with Eclipse, which has an earlier natural senescence (96 d maturity) compared with Zorro and Zenith (100 d maturity) (Kelly et al. 2014). While the greater desiccation was true in many instances, there were some cases where desiccation for Zenith was similar to Eclipse and greater than Zorro. The greatest differences in black bean desiccation were observed for the early preharvest application timings. In most instances, preharvest treatments of paraquat and saflufenacil were associated with quicker desiccation than glyphosate provided at 3, and often times, 7 DAT. This is similar to results reported by Soltani et al. (2013), where dry bean (cranberry, great northern, and white bean) desiccation with glyphosate was about 4 d behind other faster-acting herbicides, including saflufenacil. Wilson and Smith (2002) also reported dry bean (light red kidney and great northern) desiccation from glyphosate was no faster than the natural maturation, while desiccation from a faster-acting herbicide, like paraquat, was up to 20% greater than glyphosate 5 DAT for five out of six timings and years.

Black bean yield

Black bean yield data was analyzed separately by planting date, application timing and year, due to significant interactions. However, the main effects of black bean variety and preharvest treatment are presented for each planting date, application timing and year combination. Overall black bean yield was 22% greater for the first planting as compared with the second planting of black beans.

First planting date. The main effect of black bean variety indicates Zorro and Zenith out-yielded Eclipse for both the early and standard application timings in 2013 (Table 2.3). However, in 2014, there were no differences in yield among the three varieties for the early and standard application timings. The main effect of preharvest treatment indicated that saflufenacil had the greatest impact on reducing yields. Black bean yields were 25 and 63% lower for the early application timing of saflufenacil in 2013 and 2014, respectively, when compared with the nontreated control. Reductions in yield were also observed in 2013 and 2014 from early applications of paraquat and in 2014 from glyphosate applications.

In 2013, there was an interaction between the main effects of variety and preharvest treatment for the early application timing. The interaction followed the same trend as the main effects, except there was no difference between preharvest treatments applied to Eclipse. At the standard application timing, when beans were more mature, preharvest treatments did not reduce yield compared with the nontreated control in 2013. However in 2014, glyphosate and saflufenacil applications both resulted in about 18% lower black bean yield compared with the nontreated control.

Second planting date. Compared to the first planting, black bean yields were lower for Zorro compared with Eclipse and Zenith (9 and 15%, respectively) in 2013 (Table 2.3). Zorro also had 8% lower yields than Eclipse for the standard application timing in 2014. However, no differences in variety yields were observed for the standard application timing in 2013, or the early application timing in 2014. All three preharvest herbicides at the early application were not different for yield compared with the nontreated control in 2013. However in 2014, the greatest yield reduction was observed from early applications of saflufenacil (20%), followed by glyphosate (9%), and paraquat was not different from glyphosate and the nontreated control. Yield at the standard application timing in 2014, was also reduced by glyphosate and saflufenacil (11 and 15%, respectively).

Overall, variety yields in the first planting were only lower for Eclipse in 2013, for the early and standard application timings. Yields for black bean varieties in the second planting were lower for Zorro in 2013 for the early application timing and in 2014 for the standard application timing. Kelly et al. (2014) reported 6 and 11% lower yields for Zorro and Eclipse, respectively, compared with Zenith grown at 34 locations in Michigan, New York, and Ontario. In both years, saflufenacil had the greatest impact on black bean yield in the first planting, when applied at the early application timing. Generally, applications of paraquat and glyphosate also resulted in lower yields than in the nontreated control. This may be attributed to the faster herbicide activity as observed with desiccation 3 DAT (Table 2.1 and 2.2). Preharvest treatments applied at the standard application timing did not reduce yield in 2013, however 11 to 19% lower yields were observed in 2014 for both planting dates.

McNaughton et al. (2015) reported 17% lower dry bean (kidney, navy, cranberry, pinto, and great northern) yield when glyphosate was applied at 0% maturity, and 25 and 34% lower yields when saflufenacil was applied at 0 and 50% maturity, respectively. There was no impact on yield when glyphosate was applied at 25% maturity and when saflufenacil was applied at 100% maturity, when compared with the nontreated control. Wilson and Smith (2002) also reported 24% lower dry bean (light red kidney and great northern) yield for glyphosate applications made when 5 to 7% of the pods were yellow, in one of the study years. These researchers attributed differences in yield to variations in environmental conditions during the growing season. Preharvest treatments applied when 77 to 85% of pods were yellow did not result in lower yields, compared with the nontreated control.

Black bean seed quality and color

Seed weight and germination. The main effects of variety and preharvest treatments are presented for black bean seed weight and germination, combined over application timings. In three out of four planting dates and years, Zenith had the largest seed size, followed by Zorro and Eclipse (Table 2.4). There was no difference among preharvest treatments in three out of four planting dates and years for seed weight. The lowest seed germination was observed with Eclipse in 2014, for both planting dates, but preharvest treatments had no impact on germination.

Seed color. After harvest, black bean seed color L* value did not differ for variety or preharvest treatment for either planting date in 2013, when combined over application timings (Table 2.5 and 2.6). However, differences among L* values for black bean variety in 2014 indicate lighter color for Zorro when compared with Zenith and Eclipse, except for the early timing in 2014 when Zorro was only lighter than Eclipse. There was an interaction between black bean variety and preharvest treatment for the seed color value a* (red to green) in 2013 (Table 2.5). The a* value deviated the most from 0 (gray) when glyphosate was applied to Eclipse and Zorro. Main effects indicate glyphosate applied at the early timing in 2014, for the first planting, resulted in a higher a* value (more red) than the nontreated control.

Overall, preharvest treatments had no impact on the darkness (L* value) of black bean seeds. Black bean seed weight and germination mainly differed by variety and not by preharvest treatments. Differences in variety seed weights were reported by Kelly et al. (2014), with Zenith having a higher seed weight (21.7 g) than Zorro (20.2 g) or Eclipse (20.1 g). Wilson and Smith (2002) found that dry bean seed weight was reduced by 6 to 20% in one study-year when preharvest treatments were applied before 77% of the pods were yellow. They also reported a slight reduction in seed germination (up to 5%) when preharvest treatments, including paraquat, were applied when 5 to 7% of the pods were yellow, but not when 36 to 61% of the pods were yellow.

Canned bean quality and color

Hydration coefficient, washed-drained coefficient, and texture. Data for the canned bean quality measurements of hydration coefficient, washed-drained coefficient, and texture, were separated by planting dates and years because of significant interactions. In the first planting, hydration coefficients were combined over preharvest application timings for 2013, but were presented separately for 2014, due to significant interactions. Lower hydration coefficients were observed with Eclipse, when compared with Zorro and Zenith, by 4% in 2013 and about 20% in 2014, combined over application timings (Table 2.7). However, Eclipse had 2% higher washed-drained coefficients than Zorro in 2013 and approximately 20% higher in 2014. Eclipse had firmer texture (53.4 to 56.1 kg) than Zorro (45.8 to 54.3 kg) and Zenith (41.1 to 48.8 kg) in both years. Preharvest herbicide treatments did not impact hydration coefficient, washed-drained coefficient, or texture, except for the washed-drained coefficient for the first planting in 2013, where all treatments were 1 to 2% less than the nontreated control.

Preharvest application timings in the second planting were combined, except for the hydration coefficient values in 2013. The main effect of black bean variety in the second planting follows the same trend as the first planting for hydration coefficient, washed-drained coefficient, and texture (Table 2.8). Preharvest treatments did not impact hydration coefficient or washed-drained coefficient, but did lower texture by 5% when glyphosate and saflufenacil were applied in 2014 for both application timings.

Black bean variety had the greatest effect on hydration coefficient, washed-drained coefficient, and texture. Generally, Eclipse had the lowest hydration coefficient and the highest washed-drained coefficient and texture. Preharvest treatments usually had no effect on hydration coefficient, washed-drained coefficient, and texture. Texture measurements were under the ideal 55 to 65 kg range (Hosfield and Uebersax 1980); this is attributed to the processing methods from the canning protocol. Differences among black bean varieties for texture have been reported. Kelly et al. (2014) also reported that Eclipse had firmer texture (47 kg) than Zorro (43 kg) and Zenith (41 kg).

Panel evaluation of canned bean color and appearance. Panel evaluations of color and appearance were significant between planting dates, years, and preharvest application timings, so results are presented separately. There was an interaction between black bean variety and preharvest treatments for the panel evaluation means at the early application timing for both years and the standard timing in 2013 (Table 2.9). The panel color evaluations for the first planting followed the same trend as the second planting. Preharvest applications of glyphosate made at the early application timing to Zorro and Zenith resulted in 14 to 29% lighter bean color than their nontreated counterparts. However, glyphosate applied to Eclipse generally had less of an impact on color; this is attributed to the faster natural maturation of Eclipse compared with Zorro and Zenith. The main effects for the early application timings in 2014 follow the same trend, with the lightest black bean variety being Eclipse and glyphosate having the greatest impact on color compared with the other treatments (Table 2.10). Few differences in appearance evaluations existed, but generally lower ratings were observed for the black bean variety Eclipse for both planting dates and years (Table 2.9 and 2.10).

Color evaluations for black bean varieties at the standard application timing followed the same trend as the early timing, regardless of planting date and year. Zenith had the darkest color, followed by Zorro, then Eclipse with the lightest color (Table 2.11). Preharvest herbicides did not affect color at the standard timing, except for the first planting in 2014, where slightly lighter color was observed when glyphosate and saflufenacil were applied, compared with the nontreated control. Zenith had the highest appearance evaluations for both years of the first planting, while Zorro ranked higher for the second planting in 2013. An interaction between the main effects of black bean color and preharvest herbicides was significant for the second planting in 2014. Glyphosate and saflufenacil applied at the standard timing to Zorro had the greatest impact on appearance, compared with the nontreated control.

Measured canned color. Canned color L*, a*, and b* values were significant between planting dates, years, and preharvest application timings, so results are presented separately. The main effect of black bean variety indicated the darkest canned bean color (lower L* value) with Zenith (ranging from 13.2 to 14.6), while Eclipse had the lightest color (ranging from 17.2 to 19.0), at the early preharvest application timing for both planting dates and years (Table 2.12). Zenith also had a* and b* values that deviated the least from zero at the early application timing, compared with Zorro and Eclipse. Glyphosate applied at the early preharvest application timing resulted in lighter canned bean color for three out of four planting dates and years when compared with the nontreated control, combined over black bean varieties. The greatest impact on a* and b* values were also observed from early preharvest applications of glyphosate. Preharvest treatments made at the standard application timing did not affect L*, a*, or b* values (Table 2.13). The same trend of Zenith having the darkest color and Eclipse having the lightest color was also observed for the standard preharvest application timing, except for the first planting in 2013 where Zorro was not different than Eclipse for the a* measurement.

Pearson's correlation coefficients indicate a negative correlation between canned bean color values and the panel color evaluations. The canned color values of L*, and b* were strongly correlated with the panel color evaluations, by 70 and 76%, while the a* value was correlated by 58%, respectively (Table 2.14). Therefore, these correlations indicate that the black bean color measurements are a strong indication of perceived black bean color.

Overall, the highest appearance and color was observed with the black bean variety Zenith, while Eclipse generally had the lowest appearance and color ratings. The greatest impact on black bean color was observed when glyphosate was applied at the early application timing. Variety genetics are believed to be the main determinant of dry bean quality, including color. Similar differences in canning quality and color among the black bean varieties Eclipse, Zorro, and Zenith were reported by Kelly et al. (2014). Canning quality evaluations (over 4 years and 13 locations) resulted in Zenith ranking the highest in visual appearance, receiving a 4.5 out of 5 with Zorro at 4.0 and Eclipse receiving a 3.6. These researchers also found the same trend for visual color assessment after canning. Zenith (4.6) was reported to have the highest evaluation for visual color assessment, followed by Zorro (3.5), and Eclipse (2.3). Measured color values of black bean varieties indicated Zenith (13.1) had the darkest color (lowest L* value), followed by Zorro (15.8), and Eclipse (18.1).

In our study, preharvest treatments of glyphosate applied at the early application timing resulted in the lightest color of canned black beans, which may be attributed to glyphosate affecting the anthocyanin accumulation. A study by Duke et al. (1979) reported applications of glyphosate to soybean seedlings had a negative impact on the hydroxyphenolic compound levels. Another study, by Hoagland (1980), reported a substantial reduction in anthocyanins when glyphosate was applied to soybean seedlings. Hoagland (1980) reported a 44% anthocyanin reduction per gram of fresh weight of soybean compared with the control and a 49% anthocyanin reduction per soybean hypocotyl compared with the control. The impact of glyphosate on the anthocyanins of immature soybean plants suggests glyphosate could impact the anthocyanins of black beans when applied prior to physiological maturity. Reductions in black bean anthocyanin accumulation would result in a lighter color bean and may explain the black bean color loss observed when glyphosate was applied at the early application timing.

Conclusions

The greatest black bean desiccation was observed from preharvest treatments of paraquat and saflufenacil 3 DAT, while glyphosate was generally similar to the nontreated control. Preharvest herbicide applications applied prior to physiological maturity resulted in lower black bean yield than applications made at the standard application timing (pods = 80% yellow). The largest yield reductions were observed when saflufenacil was applied at the early application timing. This is likely due to the faster-acting herbicide halting development of the plant. Generally, preharvest herbicides did not impact black bean seed weight and seed germination, however black bean variety influenced seed weight and germination. Preharvest herbicide applications generally did not affect the seed color of black beans prior to canning.

Canned bean quality, including hydration coefficient, washed-drained coefficient, texture, and appearance, were usually only influenced by black bean variety and not preharvest herbicide treatments. Black bean varieties followed the same trend for color, where Zenith was the darkest, followed by Zorro, then Eclipse with the lightest color after canning. Preharvest herbicide treatments only affected color when applied at the early application timing, with the greatest impact observed when glyphosate was applied at the early timing. Preharvest herbicides are labeled for use at physiological maturity (pods = 80% yellow) and most growers strive to apply preharvest herbicides at physiological maturity. Unfortunately, uneven maturation is common with dry beans, which may leave some beans in the field at the 50% yellow pod stage, so growers should be conscious of maturity variation within a field. Black bean variety can have a significant impact on black bean color after canning, so the canning industry should also work with growers to ensure proper variety selection.

APPENDICES

APPENDIX A

Chapter 2 Tables

Table 2.1. Interactions of black bean variety and preharvest treatment on black bean desiccation 3 and 7 DAT, when beans were treated at the early (pods = 50% yellow) and standard (pods = 80% yellow) timing, and planted on two different dates in 2013 and 2014 at Richville, MI. P-values are presented for the main effects and interactions.[a]

		First planting[b]					Second planting[c]			
		Early timing			Standard timing		Early timing			Standard timing
		2013		2014	2013		2013	2014		2013
Variety	Treatment	3 DAT	7 DAT	7 DAT	3 DAT	7 DAT	7 DAT	3 DAT	7 DAT	7 DAT
		%		%	%		%	%		%
Eclipse	nontreated	88 d	94 c	84 d	98 a	99 a	87 c	75 d	99 a	99 a
	glyphosate	88 d	98 ab	95 b	98 a	99 a	96 a	83 c	99 a	99 a
	paraquat	98 a	99 a	99 a	98 a	98 b	96 a	90 ab	99 a	99 a
	saflufenacil	93 c	99 a	99 a	98 a	99 a	99 a	91 a	99 a	99 a
Zorro	nontreated	70 g	88 d	73 e	91 b	96 c	65 e	65 e	96 d	97 b
	glyphosate	70 g	96 bc	95 b	92 b	97 c	73 d	73 d	98 b	99 a
	paraquat	94 bc	99 a	97 ab	98 a	99 a	86 c	86 bc	99 a	99 a
	saflufenacil	84 e	99 a	98 ab	99 a	99 a	98 a	90 ab	99 a	99 a
Zenith	nontreated	63 h	86 d	68 f	93 b	97 c	85 c	63 e	97 c	98 b
	glyphosate	63 h	96 bc	83 d	97 a	98 b	88 bc	74 d	98 b	98 b
	paraquat	96 ab	99 a	96 ab	98 a	99 a	96 ab	86 bc	99 a	99 a
	saflufenacil	79 f	99 a	98 ab	98 a	99 a	99 a	91 a	99 a	99 a
Effects		p-values								
Variety		<0.0001	<0.0001	<0.0001	0.0014	0.0013	<0.0001	<0.0001	<0.0001	0.0136
Treatment		<0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0036
Variety*Treatment		<0.0001	0.0004	<0.0001	0.0043	0.0046	0.0005	0.0065	<0.0001	0.1573

[a] Means followed by the same letter within a column are not different at $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13, 2013 and June 5, 2014.
[c] Planting dates were June 26, 2013 and June 27, 2014.

Table 2.2. Main effect of black bean variety and preharvest treatment on black bean desiccation 3 and 7 DAT, when beans were treated at the early (pods = 50% yellow) and standard (pods = 80% yellow) timing, and planted on two different dates in 2013 and 2014 at Richville, MI. P-values are presented for the main effects and interactions.[a]

	First planting[b]			Second planting[c]			
	Early timing	Standard timing		Early timing	Standard timing		
	2014	2014		2013	2013		2014
Main effects	3 DAT	3 DAT	7 DAT	3 DAT	3 DAT	7 DAT	3 DAT
Variety	%	%		%	%		%
Eclipse	78 a	98 a	99 a	88 a	94 a	98 a	98 a
Zorro	68 b	95 c	98 b	70 b	87 b	97 b	93 b
Zenith	68 b	96 b	99 a	82 a	93 a	98 a	93 b
Treatment							
nontreated	60 c	94 c	97 b	69 c	86 c	96 b	92 b
glyphosate	68 b	95 b	99 a	77 b	90 b	98 a	96 a
paraquat	79 a	98 a	99 a	79 b	91 b	98 a	96 a
saflufenacil	77 a	98 a	99 a	95 a	98 a	99 a	95 a
Effects	p-values						
Variety	<0.0001	<0.0001	0.0124	<0.0001	0.0021	0.0136	<0.0001
Treatment	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	0.0036	0.0063
Variety*Treatment	0.6862	0.0604	0.0731	0.2085	0.4135	0.1573	0.1104

[a] Means followed by the same letter within a column are not different at $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13, 2013 and June 5, 2014.

[c] Planting dates were June 26, 2013 and June 27, 2014.

Table 2.3. Main effect of black bean variety and preharvest treatment on black bean yield, when beans were treated at the early (pods = 50% yellow) and standard (pods = 80% yellow) timing, and planted on two different dates in 2013 and 2014 at Richville, MI. P-values are presented for the main effects and interactions.[a]

	First planting[b]				Second planting[c]			
	Early timing		Standard timing		Early timing		Standard timing	
Main effects	2013	2014	2013	2014	2013	2014	2013	2014
Variety	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
Eclipse	2240 b	2264 a	2321 b	2744 a	1848 a	1993 a	1845 a	2179 a
Zorro	2501 a	2064 a	2748 a	2731 a	1681 b	1843 a	1834 a	1994 b
Zenith	2419 a	2148 a	2821 a	2627 a	1972 a	1990 a	1945 a	2080 ab
Treatment								
nontreated	2655 a	2891 a	2632 a	3014 a	1855 ab	2128 a	1880 a	2244 a
glyphosate	2624 a	2387 b	2665 a	2476 b	1963 a	1932 b	1830 a	2003 b
paraquat	2281 b	2289 b	2552 a	2858 a	1765 b	2015 ab	1789 a	2191 a
saflufenacil	1987 c	1067 c	2670 a	2455 b	1752 b	1692 c	1999 a	1900 b
Effects	p-value							
Variety	0.0085	0.1054	<0.0001	0.5330	0.0005	0.0622	0.2826	0.0067
Treatment	<0.0001	<0.0001	0.6978	<0.0001	0.0294	<0.0001	0.0842	<0.0001
Variety*Treatment	0.0004[d]	0.1108	0.9221	0.9728	0.3330	0.9480	0.4964	0.2388

[a] Means followed by the same letter within a column are not different at $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13, 2013 and June 5, 2014.

[c] Planting dates were June 26, 2013 and June 27, 2014.

[d] There was an interaction among the main effect of variety and treatment for black bean yield for the first planting - early application timing in 2013. In general, the interaction followed the main effects of variety and preharvest treatment with one exception. There was no difference among preharvest herbicide treatments and the nontreated control for Eclipse (ave. yield 2240 kg ha^{-1}).

Table 2.4. Main effect of black bean variety and preharvest treatment on black bean seed weight and percent germination after harvest for beans planted on two different dates in 2013 and 2014 at Richville, MI. Data are combined over preharvest application timings. P-values are presented for the main effects and interactions.[b]

	Seed weight				Germination			
	First planting[c]		Second planting[d]		First planting[c]		Second planting[d]	
Main effects	2013	2014	2013	2014	2013	2014	2013	2014
Variety	g 100 seeds^{-1}		g 100 seeds^{-1}		%		%	
Eclipse	17.1 c	18.9 c	17.4 a	18.4 c	98 a	84 c	97 a	91 b
Zorro	17.9 b	19.8 b	17.3 a	19.2 b	99 a	94 b	95 a	97 a
Zenith	18.7 a	20.4 a	17.7 a	20.0 a	100 a	97 a	96 a	98 a
Treatment								
nontreated	18.0 ab	20.5 a	17.5 a	19.4 a	99 a	93 a	96 a	95 a
glyphosate	17.9 ab	19.3 b	17.3 a	18.9 a	99 a	93 a	96 a	96 a
paraquat	17.6 b	19.6 b	17.7 a	18.9 a	99 a	91 a	96 a	95 a
saflufenacil	18.2 a	19.3 b	17.5 a	19.5 a	99 a	92 a	97 a	96 a
Effects	p-value							
Variety	<0.0001	<0.0001	0.1590	<0.0001	0.0289	<0.0001	0.2429	<0.0001
Treatment	0.0487	0.0001	0.4761	0.0553	0.7512	0.0001	0.8710	0.8175
Variety*Treatment	0.1690	0.6596	0.4107	0.5516	0.1690	0.6596	0.5461	0.5863

[a] Preharvest treatments were made when beans were at 50% yellow pods (early timing) and 80% yellow pods (standard timing).

[b] Means followed by the same letter within a column are not different at $\alpha \leq 0.05$ level of significance.

[c] Planting dates were June 13, 2013 and June 5, 2014.

[d] Planting dates were June 26, 2013 and June 27, 2014.

Table 2.5. Main effects of black bean variety and preharvest treatment on black bean seed L*, a*, and b* color values at the early (pods = 50% yellow) and standard (pods = 80% yellow) application timings for the first planting.[a, b]

Main effects	2013[c, d] L*[e]	2013 a*[f]	2013 b*	2014 L* Early[g]	2014 L* Standard	2014 a* Early	2014 a* Standard	2014 b* Early	2014 b* Standard
Variety									
Eclipse	16.0 a	0.13 b	-0.36 a	21.8 a	21.7 a	0.22 a	0.22 a	-0.84 c	-0.91 b
Zorro	15.9 a	-0.04 a	-0.24 a	22.2 b	22.0 b	0.24 a	0.21 a	-0.65 b	-0.89 b
Zenith	15.8 a	0.06 b	-0.21 a	22.0 ab	22.2 b	0.31 b	0.30 b	-0.45 a	-0.63 a
Treatment									
nontreated	16.2 a	0.01 a	-0.34 a	22.0 a	22.0 a	0.24 a	0.26 a	-0.85 b	-0.75 a
glyphosate	15.8 a	0.10 a	-0.42 a	22.0 a	22.0 a	0.32 b	0.25 a	-0.50 a	-0.79 a
paraquat	16.1 a	0.04 a	-0.13 a	21.8 a	22.0 a	0.24 a	0.22 a	-0.70 ab	-0.86 a
saflufenacil	15.7 a	0.06 a	-0.19 a	22.2 a	22.0 a	0.23 a	0.25 a	-0.53 a	-0.85 a
Effects	p-value								
Variety	0.6959	<0.0001	0.4750	0.0169	0.0013	<0.0001	<0.0001	0.0012	0.0294
Treatment	0.1517	0.1337	0.2150	0.0954	0.9942	0.0005	0.4793	0.0116	0.8084
Variety*Treatment	0.1678	0.0030	0.2009	0.2304	0.7293	0.0818	0.9820	0.1722	0.9356

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13, 2013 and June 5, 2014.

[c] Data in 2013 were combined over preharvest application timing.

[d] Data were combined over preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

[e] L* represents lightness (100 is white and 0 is black), a* represents red/green (positive values are redness, 0 is gray, and negative values are greenness), and b* represents yellow/blue (positive values are yellowness, 0 is gray, and negative values are blueness).

[f] There was an interaction between the main effects variety and herbicide.

[g] Preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

Table 2.6. Main effects of black bean variety and preharvest treatment on black bean seed L*, a*, and b* color values for the second planting, combined over preharvest application timings.[a, b]

Main effects	2013 L*[c]	2013 a*	2013 b*	2014 L*	2014 a*	2014 b*
Variety						
Eclipse	15.7 a	0.10 b	-0.38 a	22.1 a	0.22 a	-0.59 a
Zorro	15.7 a	0.00 a	-0.18 a	22.4 b	0.24 a	-0.59 a
Zenith	15.9 a	0.12 b	-0.34 a	22.2 a	0.28 b	-0.51 a
Treatment						
nontreated	16.0 a	0.06 a	-0.21 a	22.2 a	0.24 a	-0.56 a
glyphosate	15.7 a	0.07 a	-0.39 a	22.2 a	0.26 a	-0.56 a
paraquat	15.8 a	0.09 a	-0.40 a	22.2 a	0.24 a	-0.55 a
saflufenacil	15.8 a	0.07 a	-0.19 a	22.3 a	0.25 a	-0.59 a
Effects	p-value					
Variety	0.6610	0.0019	0.3726	0.0003	0.0003	0.1065
Treatment	0.7898	0.7967	0.5182	0.3984	0.7575	0.8069
Variety*Treatment	0.8951	0.3774	0.0832	0.7748	0.8542	0.7396

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 26, 2013 and June 27, 2014.

[c] L* represents lightness (100 is white and 0 is black), a* represents red/green (positive values are redness, 0 is gray, and negative values are greenness), and b* represents yellow/blue (positive values are yellowness, 0 is gray, and negative values are blueness).

Table 2.7. Main effects of black bean variety and preharvest treatment on texture, washed-drained coefficient, and hydration coefficient for the first planting.[a, b]

	Hydration coefficient[c]			Washed-drained coefficient[d]			Texture[e]	
		2014			2014			
Main effects	2013[f]	Early[g]	Standard	2013	Early	Standard	2013	2014
Variety							kg	
Eclipse	1.60 b	1.12 b	1.14 c	1.52 a	2.20 a	2.17 a	53.4 a	56.1 a
Zorro	1.67 a	1.43 a	1.39 b	1.49 b	1.73 b	1.77 b	45.8 b	54.3 b
Zenith	1.68 a	1.40 a	1.45 a	1.50 ab	1.74 b	1.68 c	41.1 c	48.8 c
Treatment								
nontreated	1.63 a	1.34 a	1.34 a	1.52 a	1.87 a	1.87 a	45.7 a	52.2 a
glyphosate	1.65 a	1.32 a	1.32 a	1.49 b	1.88 a	1.87 a	47.3 a	54.1 a
Paraquat	1.66 a	1.29 a	1.32 a	1.49 b	1.93 a	1.87 a	47.4 a	53.1 a
saflufenacil	1.65 a	1.33 a	1.32 a	1.50 b	1.88 a	1.87 a	46.6 a	52.8 a
Effects	p-value							
Variety	<0.0001	<0.0001	<0.0001	0.0099	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.0710	0.1675	0.5683	0.0297	0.2430	0.9888	0.0779	0.1279
Var.*Trt.	0.2623	0.8096	0.7828	0.0724	0.4093	0.7157	0.8089	0.7974

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13, 2013 and June 5, 2014.

[c] Hydration coefficient is the ratio of the soaked bean to the dry bean weight.

[d] Washed-drained coefficient is the ratio of the washed-drained bean weight to the soaked bean weight.

[e] Texture is the force (kg) required to crush a 100 g sample of processed beans.

[f] Data were combined over preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

[g] Preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

Table 2.8. Main effects of black bean variety and preharvest treatment on texture, washed-drained coefficient, and hydration coefficient for the second planting.[a, b]

Main effects	Hydration coefficient[c] 2013 Early[g]	Hydration coefficient[c] 2013 Standard	Hydration coefficient[c] 2014[f]	Washed-drained coefficient[d] 2013	Washed-drained coefficient[d] 2014	Texture[e] 2013	Texture[e] 2014
						kg	kg
Variety							
Eclipse	1.60 b	1.63 c	1.16 c	1.52 b	2.12 a	51.7 a	52.7 a
Zorro	1.69 a	1.69 a	1.37 b	1.49 c	1.82 b	44.6 b	49.6 b
Zenith	1.68 a	1.66 b	1.43 a	1.56 a	1.73 c	40.0 c	44.4 c
Treatment							
nontreated	1.65 a	1.67 a	1.32 a	1.52 a	1.90 a	45.2 a	49.9 a
glyphosate	1.67 a	1.67 a	1.33 a	1.50 a	1.88 a	45.6 a	47.5 b
paraquat	1.65 a	1.66 a	1.32 a	1.54 a	1.90 a	45.1 a	50.8 a
saflufenacil	1.65 a	1.66 a	1.32 a	1.52 a	1.90 a	45.8 a	47.6 b
Effects	p-value						
Variety	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.5619	0.4580	0.8818	0.2558	0.8853	0.8137	<0.0001
Var.*Trt.	0.9732	0.2096	0.2048	0.1355	0.3631	0.6650	0.5715

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 26, 2013 and June 27, 2014.

[c] Hydration coefficient is the ratio of the soaked bean to the dry bean weight.

[d] Washed-drained coefficient is the ratio of the washed-drained bean weight to the soaked bean weight.

[e] Texture is the force (kg) required to crush a 100 g sample of processed beans.

[f] Data were combined over preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

[g] Preharvest herbicide application timings: early (50% yellow pods) and standard (80% yellow pods).

Table 2.9. Effect of black bean variety by preharvest treatment interaction on the panel evaluation means at the early (pods = 50% yellow) preharvest application timing.[a]

		First planting[b]				Second planting	
		2013		2014		2013	
Variety	Treatment	Color[c]	Appearance	Color	Appearance	Color	Appearance
Eclipse	nontreated	2.43 e	3.18 de	3.07 f	3.41 e	2.28 f	3.07 f
	glyphosate	2.23 f	3.19 c-e	2.41 h	3.38 e	2.31 f	3.10 ef
	paraquat	2.22 f	2.76 f	3.04 f	3.42 e	2.36 f	3.13 d-f
	saflufenacil	2.37 ef	3.07 e	3.02 f	3.31 e	2.43 f	3.31 b-e
Zorro	nontreated	3.38 c	3.32 b-d	3.81 c	3.86 cd	3.33 d	3.42 a-c
	glyphosate	2.89 d	3.11 de	2.69 g	3.96 bc	2.82 e	3.51 ab
	paraquat	3.31 c	3.23 de	3.35 e	3.98 bc	3.34 d	3.55 a
	saflufenacil	3.39 c	3.40 bc	3.71 c	3.77 d	3.20 d	3.45 a-c
Zenith	nontreated	4.48 a	3.27 b-e	4.74 a	4.18 a	4.63 a	3.33 a-d
	glyphosate	3.48 c	3.48 b	3.52 d	3.89 cd	4.19 c	3.50 ab
	paraquat	4.27 b	3.80 a	4.50 b	4.09 ab	4.53 ab	3.06 f
	saflufenacil	4.31 ab	3.32 b-d	4.62 ab	4.23 a	4.39 b	3.26 c-f
Effects		———	———	——— p-value ———	———	———	———
Variety		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment		<0.0001	0.9999	<0.0001	0.2936	<0.0001	0.1774
Variety*Treatment		<0.0001	<0.0001	<0.0001	0.0011	<0.0001	0.0093

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

[c] Color and appearance evaluated by a trained panel, using a scale from 1 (unacceptable) to 5 (excellent).

Table 2.10. Main effects of black bean variety and preharvest treatment on the panel evaluation means at the early (pods = 50% yellow) preharvest application timing for the second planting of 2014.[a, b]

Main effects	Color[c]	Appearance
Variety		
Eclipse	3.14 c	3.76 b
Zorro	3.57 b	3.93 a
Zenith	4.69 a	3.94 a
Treatment		
nontreated	3.89 a	3.93 a
glyphosate	3.61 b	3.88 a
paraquat	3.83 a	3.98 a
saflufenacil	3.87 a	3.72 b
Effects	p-value	
Variety	<0.0001	0.0002
Treatment	<0.0001	<0.0001
Variety*Treatment	0.3919	0.1149

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting date was June 27, 2014.

[c] Color and appearance evaluated by a trained panel, using a scale from 1 (unacceptable) to 5 (excellent).

Table 2.11. Main effects of black bean variety and preharvest treatment on the panel evaluation means at the standard (pods = 80% yellow) preharvest application timing.[a]

Main effects	First planting[b]				Second planting			
	2013		2014		2013		2014	
	Color[c]	Appearance	Color	Appearance	Color	Appearance	Color	Appearance[d]
Variety								
Eclipse	2.47 c	3.20 b	3.09 c	3.31 c	2.50 c	3.10 b	3.26 c	3.76 b
Zorro	3.20 b	3.18 b	3.78 b	3.92 b	3.47 b	3.42 a	3.66 b	3.93 a
Zenith	4.56 a	3.41 a	4.65 a	4.19 a	4.68 a	3.10 b	4.88 a	3.94 a
Treatment								
nontreated	3.45 a	3.23 b	3.91 a	3.78 a	3.55 a	3.21 a	3.92 a	3.93 a
glyphosate	3.40 a	3.27 ab	3.79 b	3.81 a	3.51 a	3.18 a	3.93 a	3.9 ab
paraquat	3.34 a	3.19 b	3.85 ab	3.81 a	3.58 a	3.15 a	3.93 a	4.0 a
saflufenacil	3.46 a	3.37 a	3.82 b	3.82 a	3.57 a	3.29 a	3.94 a	3.8 b
Effects	p-value							
Variety	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.0592	0.0267	0.0031	0.8484	0.5216	0.2069	0.9436	0.0492
Var.*Trt.	0.3681	0.6429	0.0990	0.0891	0.7154	0.6990	0.4857	0.0010

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

[c] Color and appearance evaluated by a trained panel, using a scale from 1 (unacceptable) to 5 (excellent).

[d] There was an interaction between the main effects variety and herbicide.

Table 2.12. Main effects of black bean variety and preharvest treatment on L*, a*, and b* color values for the early (pods = 50% yellow) preharvest application timing.[a]

	First planting[b]						Second planting					
	2013			2014			2013			2014		
Main effects	L*[c]	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Variety												
Eclipse	19.0 c	9.3 b	7.7 c	18.0 c	12.0 c	7.3 c	18.9 c	9.3 b	7.5 c	17.2 c	10.7 c	6.0 c
Zorro	17.6 b	9.2 b	4.7 b	16.1 b	11.0 b	4.8 b	16.9 b	9.3 b	5.1 b	15.3 b	10.3 b	3.7 b
Zenith	14.6 a	7.8 a	2.8 a	14.0 a	7.6 a	1.6 a	13.2 a	7.4 a	2.5 a	13.6 a	6.2 a	0.0 a
Treatment												
nontreated	16.5 a	8.4 a	4.7 a	15.2 a	8.8 a	3.5 a	15.8 a	8.4 a	4.6 a	15.0 a	8.6 a	2.9 a
glyphosate	17.6 b	9.3 c	5.6 c	17.8 b	12.6 c	6.5 c	17.0 b	8.9 b	5.4 c	15.5 ab	9.4 c	3.7 c
paraquat	17.3 b	8.8 b	5.1 b	15.5 a	9.9 b	4.2 b	16.0 a	8.6 ab	4.9 ab	15.2 a	9.0 b	3.2 b
saflufenacil	17.0 ab	8.7 b	4.9 ab	15.7 a	9.7 b	4.0 b	16.5 ab	8.7 b	5.1 bc	15.8 b	9.1 bc	3.3 b
Effects	p-value											
Variety	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.0069	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	0.0075	0.0103	0.0005	0.0181	<0.0001	<0.0001
Var.*Trt.	0.2953	0.7000	0.6933	0.6571	0.1272	0.2254	0.4288	0.7163	0.5865	0.0573	0.4159	0.8130

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

[c] L* represents lightness (100 is white and 0 is black), a* represents red/green (positive values are redness, 0 is gray, and negative values are greenness), and b* represents yellow/blue (positive values are yellowness, 0 is gray, and negative values are blueness).

Table 2.13. Main effects of black bean variety and preharvest treatment on L*, a*, and b* color values for the standard (pods = 80% yellow) preharvest application timing.[a]

	First planting[b]						Second planting					
	2013			2014			2013			2014		
Main effects	L*[c]	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*
Variety												
Eclipse	19.0 c	9.3 b	7.5 c	17.2 c	11.4 c	6.6 c	18.2 c	9.1 c	7.3 c	16.8 c	10.5 c	5.8 c
Zorro	17.1 b	9.0 b	4.8 b	14.7 b	8.9 b	3.4 b	16.5 b	8.8 b	4.5 b	14.7 b	9.8 b	3.3 b
Zenith	13.3 a	7.3 a	2.4 a	13.5 a	6.3 a	0.7 a	12.0 a	7.0 a	2.2 a	14.0 a	5.8 a	-0.4 a
Treatment												
nontreated	16.5 a	8.4 a	4.7 a	15.1 a	8.6 a	3.4 a	15.4 a	8.3 a	4.6 a	14.9 a	8.6 a	2.8 a
glyphosate	16.4 a	8.7 a	5.0 a	14.9 a	8.8 a	3.7 a	15.6 a	8.4 a	4.8 a	15.5 a	8.8 a	3.0 a
paraquat	16.7 a	8.5 a	5.0 a	15.1 a	8.8 a	3.5 a	15.8 a	8.1 a	4.6 a	15.1 a	8.7 a	2.9 a
saflufenacil	16.3 a	8.6 a	4.9 a	15.4 a	9.3 a	3.7 a	15.4 a	8.5 a	4.8 a	15.4 a	8.6 a	2.9 a
Effects	p-value											
Variety	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment	0.5251	0.2768	0.6119	0.5541	0.2463	0.0594	0.3656	0.0623	0.3683	0.4468	0.8816	0.6960
Var.*Trt.	0.6951	0.6289	0.7561	0.9089	0.9898	0.8479	0.7510	0.1981	0.4638	0.5366	0.9732	0.8810

[a] Means followed by the same letter within a column are not statistically different at the $\alpha \leq 0.05$ level of significance.

[b] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

[c] L* represents lightness (100 is white and 0 is black), a* represents red/green (positive values are redness, 0 is gray, and negative values are greenness), and b* represents yellow/blue (positive values are yellowness, 0 is gray, and negative values are blueness).

Table 2.14. Pearson's correlation coefficients of black bean seed quality traits, combined across all planting dates, site years, and preharvest application timings.

	Color[a]	Appearance	L*[b]	a*	b*	Dry L*	Dry a*	Dry b*	HC[c]	WDC[d]	Texture[e]
Color		0.28	-0.70	-0.58	-0.76	0.23	0.15	-0.02	0.04	-0.03	-0.43
		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.079	0.000	0.004	<.0001
Appearance			-0.22	-0.08	-0.25	0.31	0.19	-0.09	-0.19	0.15	0.07
			<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
L*				0.63	0.86	-0.24	-0.19	0.04	-0.06	0.05	0.43
				<.0001	<.0001	<.0001	<.0001	0.0001	<.0001	<.0001	<.0001
a*					0.79	0.18	-0.00	-0.18	-0.46	0.47	0.60
					<.0001	<.0001	0.788	<.0001	<.0001	<.0001	<.0001
b*						-0.29	-0.21	-0.01	-0.11	0.13	0.53
						<.0001	<.0001	0.452	<.0001	<.0001	<.0001
Dry L*							0.54	-0.34	-0.80	0.73	0.38
							<.0001	<.0001	<.0001	<.0001	<.0001
Dry a*								-0.12	-0.48	0.41	0.27
								<.0001	<.0001	<.0001	<.0001
Dry b*									0.40	-0.38	-0.25
									<.0001	<.0001	<.0001
HC										-0.97	-0.59
										<.0001	<.0001
WDC											0.51
											<.0001
Texture											

[a] Color and appearance evaluated by a trained panel, using a scale from 1 (unacceptable) to 5 (excellent).

[b] L* represents lightness (100 is white and 0 is black), a* represents red/green (positive values are redness, 0 is gray, and negative values are greenness), and b* represents yellow/blue (positive values are yellowness, 0 is gray, and negative values are blueness).

[c] Hydration coefficient is the ratio of the soaked bean to the dry bean weight.

[d] Washed-drained coefficient is the ratio of the washed-drained bean weight to the soaked bean weight.

[e] Texture is the force (kg) required to crush a 100 g sample of processed beans.

APENDIX B

Table B2.1. Percent pod and leaf desiccation and percent seed moisture for black beans at the time of application for the early (pods = 50% yellow) and standard (pods = 80% yellow) timing, and planted on two different dates in 2013 and 2014 at Richville, MI.

		Early						Standard					
		2013			2014			2013			2014		
Planting [a]	Variety	Pod	Leaf	Seed	Pod	Leaf	Seed	Pod	Leaf	Seed	Pod	Leaf	Seed
		%			%			%			%		
First	Eclipse	50	80	46	65	70	70	80	95	20	95	95	22
	Zorro	40	50	66	60	50	84	70	85	30	85	90	25
	Zenith	40	50	—	50	40	84	60	90	—	85	90	27
Second	Eclipse	50	70	52	60	70	54	90	90	38	90	98	18
	Zorro	40	45	60	50	50	60	80	80	24	85	97	30
	Zenith	40	50	—	45	55	72	75	85	—	85	95	33

[a] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

Table B2.2. Mean air temperature and accumulated precipitation at Richville, MI of black beans 0, 1-3, and 4-7 DAT.[a]

			Mean air temperature			Accumulated precipitation		
			0 DAT	1-3 DAT	4-7 DAT			
Planting[b]	Application[c]	Year	High/low	High/low	High/low	0 DAT	1-3 DAT	4-7 DAT
			C			mm		
First	Early	2013	24/12	24/8	27/13	0	0	1
	Standard		25/14	17/5	22/5	0	4	7
	Early	2014	30/16	25/14	27/17	0	0	43
	Standard		27/16	26/13	23/12	0	1	12
Second	Early	2013	15/4	17/4	25/9	0	4	7
	Standard		23/2	26/4	23/8	0	0	6
	Early	2014	24/6	24/7	22/9	0	0	10
	Standard		25/9	17/10	15/7	9	2	15

[a] Mean air temperature and precipitation data were obtained from the Michigan State University Enviro-weather database (MSU Enviro-weather 2015).

[b] Planting dates were June 13 and 26, 2013 and June 5 and 27, 2014.

[c] Preharvest herbicides were applied at the early (pods = 50% yellow) and standard (pods = 80% yellow) timing.

Table B2.3. Monthly precipitation means and 30-yr average for Richville, MI during the 2013 and 2014 growing season.[a]

	Precipitation		
Month	2013	2014	30 yr. ave.
	cm		
June	4.4	7.0	8.6
July	5.2	10.6	8.4
August	4.7	10.0	7.6
September	1.5	7.7	9.5
October	8.3	5.3	7.3
Total for growing season	24.0	40.5	41.5

[a] Precipitation data were obtained from the Michigan State University Enviro-weather database (MSU Enviro-weather 2015) and 30 yr average data were obtained from the Michigan State Climatologist's office (MI Climatologists 2015).

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