3. Laboratory and field evaluation of seed treatments for control of crucifer and striped flea beetles in hybrid canola at different temperatures and moisture conditions

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SUMMARY

With funding from SaskCanola, Canola Clusters and private industry, laboratory and field tests were conducted in 2011-2015 to evaluate seed treatments for control of crucifer flea beetles, *Phyllotreta cruciferae* (Goeze) and striped flea beetles, *Phyllotreta striolata* F. Lab bioassays in 2011 and 2012 focused on the effect of temperature (10, 20 and 30ºC) and soil moisture (dry and wet) on the efficacy of 13 seed treatments against each flea beetle species. The treatments included untreated seed, a fungicide check (Tribune), four neonicotinoid seed treatments (Gaucho CS FL, Prosper FX, Helix and Helix XTra), two diamide seed treatments (Lumiderm and Fortenza), two experimental seed treatments (EX 1 and EX 2) and three diamide/neonicotinoid mixtures (Lumiderm/Prosper, Lumiderm/Helix XTra and Fortenza/Helix XTra). In bioassays at each temperature and moisture regime, we identified seed treatments that provide the 1) best control of crucifer and striped flea beetles; 2) best protection against feeding damage and 3) greatest improvement in seedling fresh weight. Field tests were conducted annually in 2013-2015 to evaluate the efficacy of the seed treatments against flea beetles in Roundup Ready (RR) canola, Clearfield (CL) canola and canola mustard. Sticky cards were used to monitor populations of crucifer, striped and hop flea beetles throughout the growing season. The relative abundance of each species during emergence and stand establishment varied greatly depending on the year and seeding date. In each test, we identified seed treatments that provide the 1) best protection against flea beetle damage, 2) best emergence and stand establishment and 3) greatest improvements in fresh weight, shoot biomass and seed yield.

Laboratory bioassays 2011

Lab bioassays were conducted in 2011 to assess the influence of temperature and soil moisture on the efficacy of seed treatments against crucifer and striped flea beetles. The treatments included untreated seeds and seeds treated with Tribune, Gaucho CS

FL, Helix, Prosper FX, Helix XTra, Lumiderm, Fortenza, Lumiderm/Prosper mixture and two experimental seed treatments (EX 1 and EX 2). Untreated and treated seeds were grown in dry medium (20-30% moisture content) and wet medium (70-100% moisture content). Seedlings from each moisture regime were exposed to crucifer or striped flea beetles (n = 20 beetles/cage) at the cotyledon stage for 72 h at 10, 20 and 30ºC. Bioassays were replicated four times using a randomized split-split plot design with temperature as main plots, seed treatments as subplots and soil moisture as sub subplots. Flea beetle mortality, feeding damage and seedling fresh weight varied significantly depending on temperature, seed treatment and soil moisture. Two-way and three-way interactions on each variable were significant so treatment data at each temperature and moisture regime were analyzed separately.

Temperature and soil moisture had a significant effect on the efficacy of seed treatments against crucifer flea beetles. At each temperature and moisture regime, plants grown from untreated seeds or Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling fresh weight. Damage in the check treatments in wet and dry soil was lowest at 10ºC (4-5% damage), intermediate at 20ºC (13-15% damage) and highest at 30ºC (28-45% damage). In most instances, Prosper FX, Helix XTra and the Lumiderm/Prosper mixture provided the best control of crucifer flea beetles in wet soil at 10ºC (22-25% mortality), 20ºC (47-61% mortality) and 30ºC (76-84% mortality) and best control of crucifer flea beetles in dry soil at 10ºC (45-58% mortality), 20ºC (75-86% mortality) and 30ºC (85-97% mortality). The treatments also provided the best protection against feeding damage after 72 h in wet soil at 10ºC (3-4% damage), 20ºC (4-5% damage) and 30ºC (4-6% damage). The treatments along with Helix and Gaucho CS FL provided the best protection in dry soil at 10ºC (3-4% damage), 20ºC (3-4% damage) and 30ºC (4-7% damage). Fortenza, Prosper FX, the Lumiderm/Prosper mixture and Lumiderm provided the greatest improvement in seedling fresh weight in wet soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in wet soil by 1.2 times at 20ºC and by 1.5-1.6 times at 30ºC. Fortenza, Lumiderm, Lumiderm/Prosper mixture and Helix XTra provided the greatest improvement in fresh weight in dry soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in dry soil by 1.2-1.3 times at 20ºC and by 1.9-2.2 times at 30ºC.

Temperature and soil moisture had a significant effect on the efficacy of seed treatments against striped flea beetles. At each temperature and moisture regime, plants grown from untreated or Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling fresh weight. Damage in the check treatments in wet and dry soil was lowest at 10ºC (5-7% damage), moderate at 20ºC (17-27% damage) and highest at 30ºC (50-75% damage). In most instances, EX 1, the Lumiderm/Prosper mixture, Fortenza and Prosper FX provided the best control of striped flea beetles in wet soil at 10ºC (7-9% mortality), 20ºC (5-10% mortality) and 30ºC (20-28% mortality). EX 1, Helix XTra, Fortenza and Lumiderm/Prosper mixture provided the best control of striped flea beetles in dry soil at 10ºC (7-29% mortality), 20ºC (8-24% mortality) and 30ºC (32-64% mortality). Fortenza, EX 1 and the Lumiderm/Prosper mixture provided the best protection against feeding damage after 72 h in wet soil at 10ºC (3-4% damage), 20ºC (4-5% damage) and 30ºC (4-6% damage). The treatments along with Gaucho CS FL provided the best protection in dry soil at 20ºC (9-12% damage) and 30ºC (8-20% damage). Helix XTra, Prosper FX, EX 1 and the Lumiderm/Prosper mixture provided the best protection in dry soil at 20ºC (6-14% damage) and 30ºC (7-15% damage). Fortenza, EX 1, Lumiderm and Lumiderm/Prosper mixture provided the greatest improvement in seedling fresh weight in wet soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in wet soil by 1.1-1.4 times at 20ºC and by 1.6-2.1 times at 30ºC. EX 1, Helix XTra, and the Lumiderm/Prosper mixture provided the greatest improvement in fresh weight in dry soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in dry soil by 1.3-1.4 times at 20ºC and by 2.4-3.1 times at 30ºC.

Laboratory bioassays 2012

Lab bioassays were repeated in 2012 to assess the influence of temperature and soil moisture on the efficacy of 10 seed treatments against crucifer and striped flea beetles. Treatments included untreated seeds and seeds treated with Tribune, Gaucho CS FL, Helix, Prosper FX, Helix XTra, Fortenza, Fortenza/Helix XTra mixture and two experimental seed treatments (EX 1 and EX 2). Untreated and treated seeds were grown in dry medium and wet medium and exposed to crucifer or striped flea beetles at the cotyledon stage for 72 h at 10, 20 and 30ºC. Bioassays were replicated four times using a randomized split-split plot design with temperature as main plots, seed treatment as subplots and soil moisture as sub subplots. Flea beetle mortality, feeding damage and seedling fresh weight varied significantly depending on temperature, seed treatment and soil moisture. Two-way and three-way interactions on each variable were significant so treatment data at each temperature and moisture regime were analyzed separately.

Temperature and soil moisture had a significant effect on the efficacy of seed treatments against crucifer flea beetles in 2012. At each temperature and moisture regime, plants grown from untreated seeds or Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling fresh weight. Damage in the check treatments in wet and dry soil after 72 h was lowest at 10ºC (4-5% damage), moderate at 20ºC (10-12% damage) and highest at 30ºC (22-51% damage). In most instances, EX 2, the Fortenza/Helix XTra mixture, Helix XTra and Prosper FX provided the best control of crucifer flea beetles in wet soil at 10ºC (15-25% mortality), 20ºC (47-59% mortality) and 30ºC (78-86% mortality). The Fortenza/Helix XTra mixture, Helix XTra, EX 2 and Prosper FX or Helix provided the best control of crucifer flea beetles in dry soil at 10ºC (41-56% mortality), 20ºC (61-84% mortality) and 30ºC (93-97% mortality). EX 2, the Fortenza/Helix XTra mixture, Helix XTra and Prosper FX provided the best protection against feeding damage after 72 h in wet soil at 10ºC (2-3% damage), 20ºC (3-4% damage) and 30ºC (4-6% damage) and the best protection in dry soil at 10ºC (2-3% damage), 20ºC (3-4% damage) and 30ºC (3-4% damage). EX 2, the Fortenza/Helix XTra mixture, Helix XTra and Helix or Prosper FX provided the greatest improvement in seedling fresh weight in wet soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in wet soil by 1.2-1.3 times at 20ºC and 30ºC. EX 2, Helix XTra, Helix and the Fortenza/Helix XTra mixture provided the greatest improvement in fresh weight in dry soil at 10ºC, 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in dry soil by 1.2-1.4 times at 20ºC and by 2.2-2.3 times at 30ºC.

Temperature and soil moisture had a significant effect on the efficacy of seed treatments against striped flea beetles. At each temperature and moisture regime, plants grown from untreated or Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling fresh weight. Damage in the check treatments in wet and dry soil after 72 h was lowest at 10ºC (6-7% damage), moderate at 20ºC (12-22% damage) and highest at 30ºC (34-66% damage). In most instances, EX 1, EX 2, Helix, Helix XTra, Prosper FX or the Fortenza/Helix XTra mixture, provided the best control of striped flea beetles in wet soil at 10ºC (1-5% mortality), 20ºC (2-18% mortality) and 30ºC (5-14% mortality). EX 1, the Fortenza/Helix XTra mixture, EX 2 and Prosper FX or Helix XTra provided the best control of striped flea beetles in dry soil at 10ºC (2-9% mortality), 20ºC (3-23% mortality) and 30ºC (42-81% mortality). Fortenza, the Fortenza/Helix XTra mixture, EX 2 and EX 1 provided the best protection against feeding damage after 72 h in wet soil at 10ºC (4-5% damage), 20ºC (7-11% damage) and 30ºC (14-20% damage). EX 1, EX 2, the Fortenza/Helix XTra mixture, Prosper FX or Helix XTra provided the best protection in dry soil at 10ºC (4-5% damage), 20ºC (5-7% damage) and 30ºC (7-13% damage). EX 2, the Fortenza/Helix XTra mixture and Prosper or Fortenza provided the greatest improvement in seedling fresh weight in wet soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in wet soil by 1.1 times at 20ºC and by 1.2-1.4 times at 30ºC. EX 2, EX 1, the Fortenza/Helix XTra mixture, Helix XTra and Prosper FX provided the greatest improvement in fresh weight in dry soil at 20ºC and 30ºC. Compared to Tribune, the treatments improved fresh weight in dry soil by 1.2-1.4 times at 20ºC and by 2.9-3.7 times at 30ºC.

Results from the bioassays in 2011 and 2012 were sent to the chemical companies and forwarded to PMRA to support the registration of the most efficacious seed treatments. Over the past 18 months, Lumiderm, Fortenza, the Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture and Fortenza/Helix XTra mixture have been registered for control of flea beetles in canola in Canada. EX 1 and EX 2 are currently under review by PMRA. After the final report was submitted, EX 1 and EX 2 were registered for control of flea beetles in canola in Canada. EX 1 containing the sulfoximide insecticide, sulfoxaflor, was registered under the trade name Rascendo. EX 2 containing a mixture of Helix XTra and Rascendo was registered under the trade name Visivio.

Field trials 2013

In 2013, field trials were conducted to evaluate the efficacy of 13 seed treatments against flea beetles in RR canola, CL canola and canola mustard. Treatments included untreated seeds and seeds treated with Tribune, Gaucho CS FL, Helix, Prosper Evergol, Helix XTra, Lumiderm, Fortenza, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture, Fortenza/Helix XTra mixture and two experimental seed treatments (EX 1 and EX 2). Tests on each canola type were replicated four times using a randomized complete block design. In the tests, air temperatures during emergence and stand establishment ranged from 2ºC to 25ºC. Rainfall was nearly twice the norm in June. Weekly flea beetle counts on yellow sticky cards (n = 25-50 beetles/card) indicated that flea beetle populations during emergence and stand establishment were relatively low in 2013. Striped flea beetles were the most abundant species when damage was assessed after 14 days whereas crucifer flea beetles were more common when damage was assessed after 21 days. In most tests, plants grown from untreated seeds or Tribune-treated seeds had the highest flea beetle damage, poorest seedling emergence and stand establishment and lowest fresh weight, shoot biomass and seed yield. Damage in check treatments after 21 days averaged 18-19% in RR canola, 15-19% in CL canola and 43-44% in canola mustard.

In each field test, seed treatments were ranked on the basis of four 'efficacy' criteria including the ability to reduce flea beetle damage to the cotyledons and improve stand establishment, shoot biomass and seed yield. Although the specific rankings of the treatments differed from test to test, the most efficacious seed treatments in 2013 included Prosper FX, Helix XTra, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture and Fortenza/Helix XTra mixture. In RR canola, the most effective seed treatments reduced flea beetle damage after 14 days by 7-9% and compared to Tribune, improved stand establishment by 7-12%, plant fresh weight by 1.1-1.3 times, shoot biomass by 1.2-1.5 times and seed yield by 4-8%. In CL canola, the most effective seed treatments reduced damage by 8-9% and improved stand establishment by 10-16% and shoot biomass by 1.4-1.7 times. The treatments had no effect on seed yield in CL canola. In canola mustard, the best seed treatments reduced flea beetle damage by 23-30% and improved stand establishment by 15-20%, fresh weight by 1.5-2.0 times, shoot biomass by 2.2-3.1 times and seed yield by 10-18%.

Field trials 2014

In 2014, field tests were conducted to evaluate the efficacy of 10 seed treatments in RR canola and canola mustard. The treatments included untreated seeds and seeds treated with Tribune, Gaucho CS FL, Helix, Prosper Evergol, Helix XTra, Fortenza, EX 1, EX 2 and the Fortenza/Helix XTra mixture. In the tests, air temperatures during emergence and stand establishment ranged from -4ºC to 31ºC. Rainfall was above-normal in May and June. Flea beetle populations were relatively high (50-200 beetles/card) during emergence and establishment. Striped flea beetles were the most abundant species in each canola type. Damage in check treatments after 21 days averaged 45-47% in RR canola and 42% in canola mustard.

The most efficacious seed treatments in 2014 included Gaucho CS FL, Prosper Evergol, Helix XTra, Fortenza, EX 2 and Fortenza/Helix XTra mixture. The most effective seed treatments in RR canola reduced flea beetle damage by 33-36% and improved stand establishment by 36-42%, plant fresh weight by 2.5-3.0 times, shoot biomass by 1.2-1.5 times and seed yield by 4-8%. The best seed treatments in canola mustard reduced flea beetle damage by 11-16% and improved stand establishment by 16-23%, fresh weight by 1.6-1.8 times, shoot biomass by 2.6-2.7 times and seed yield by 7-11%.

Field trials 2015

In 2015, field tests were conducted to evaluate the efficacy of 11 seed treatments in RR canola and CL canola. The treatments included untreated seeds and seeds treated with Tribune, Gaucho CS FL, Helix, Prosper Evergol, Helix XTra, Fortenza, EX 1, EX 2, Fortenza/Helix XTra mixture and Fortenza/Helix mixture. In the tests, air temperatures during emergence and stand establishment ranged from 6ºC to 33ºC. Rainfall was below-normal in May and June. Weekly counts on sticky cards (1000-1500 beetles/card) indicated that populations of striped flea beetles were the highest ever recorded at AAFC-Saskatoon. Damage in check treatments after 21 days averaged 63-64% in RR canola and 41% in CL canola.

The most efficacious seed treatments included Gaucho CS FL, Prosper Evergol, Helix XTra, Fortenza, EX 2, Fortenza/Helix XTra mixture and Fortenza/Helix mixture. In RR canola, the most effective seed treatments reduced flea beetle damage by 7-21% and improved stand establishment by 21-35%, plant fresh weight by 2.3-3.2 times, shoot biomass by 4.1-6.6 times and seed yield by 27-36%. The best seed treatments in CL canola reduced flea beetle damage by 9-15% and improved stand establishment by 13-26%, fresh weight by 1.5-1.6 times, shoot biomass by 1.9-2.4 times and seed yield by 12-16%. In most tests, seed treatments that provided the best protection against flea beetle damage after 14 days also provided the greatest improvements in stand establishment, fresh weight and shoot biomass.

Results from the laboratory and field tests showed that seed treatments differ in their efficacy against crucifer and striped flea beetles at different temperatures and moisture conditions. With the geographic shift in populations of crucifer and striped flea beetles in Saskatchewan in recent years, canola producers are encouraged to monitor spring and fall populations of flea beetles to select the most appropriate seed treatment.

INTRODUCTION

Flea beetles (Coleptera: Chrysomelidae) are a chronic early season pest of canola, *Brassica napus* L., in many regions of western Canada (Lamb and Turnock 1982; Soroka and Elliott 2011) and northern United States (Knodel and Olson 2002; Reddy et al. 2014). The crucifer flea beetle, *Phyllotreta cruciferae* (Goeze), is the predominant species in southern and central regions of canola production whereas the striped flea beetle, *Phyllotreta striolata* F., is most common in northern Parkland and Peace River regions (Burgess 1977, 1982, 1984; Cárcamo et al. 2008). Both species have one generation per year and overwinter in grassy areas, shelterbelts and wooded areas (Burgess 1977, 1981; Ulmer and Dosdall 2006). After breaking diapause, adults initially feed on cruciferous weeds and volunteer canola (Burgess 1977; Lamb 1983). The adults then migrate into canola fields when temperatures exceed 14°C (Lamb 1983; Tansey et al. 2015). Feeding damage is most severe at the seedling and early true-leaf stages when the weather is hot and dry (Burgess 1977; Lamb 1984). Depending on weather conditions and flea beetle densities, feeding damage may result in lower plant stands, reduced growth, delayed development, uneven maturity and lower seed yield or grade (Putnam 1977; Lamb 1984; Elliott et al. 2007). Flea beetle damage to *Brassica* oilseed crops is estimated to reduce production by 8-10% (Lamb and Turnock 1982) and result in economic losses in excess of $300 million annually in North America (Knodel and Olson 2002).

Cultural practices such as early or delayed seeding, direct seeding into stubble, higher seeding rates and planting large vigorous seed have been shown to reduce flea beetle damage (Dosdall et al. 1999; Dosdall and Stevenson 2005; Cárcamo et al. 2008; Elliott et al. 2007; Knodel et al. 2008). However, cultural practices alone may be inadequate when flea beetle populations are high and weather conditions exacerbate feeding damage. Consequently, canola producers in Canada and the United States rely on prophylactic seed treatments and foliar insecticides when flea beetles defoliate more than 25% of the cotyledons and early true leaves (Knodel and Olson 2002; Canola

Council of Canada 2015). Since 2001, seed treatments containing a neonicotinoid insecticide and fungicides have been used for control of flea beetles and seedling pathogens in canola. Seed treatments registered for flea beetle control in Canada include formulations of Gaucho (imidacloprid), Prosper (clothianidin) and Helix or Helix XTra (thiamethoxam). Neonicotinoid insecticides are absorbed by the roots and translocated to the cotyledons and leaves (Maienfisch et al. 2001). Root uptake and translocation improve with higher temperatures, application rate and solubility of the insecticide in water (Jeschke et al. 2011; Bonmatin et al. 2015). Upon ingestion, neonicotinoid insecticides disrupt neural function in insects by binding to nicotinic acetylcholine receptors in the central nervous system (Jeschke et al. 2011; Tomizawa 2013; Simon-Delso et al. 2015). Depending on concentration and chemical structure, neonicotinoids may act as an antagonist and inhibit neural activity or act as a 'super agonist' and stimulate excessive neural activity (Maienfisch et al. 2001; Brown et al. 2006; Ihara et al. 2006). By disrupting neural activity, neonicotinoids may affect locomotion and feeding at sub-lethal doses. In greenhouse experiments, Tansey et al. (2008a, 2008b) reported that clothianidin and thiamethoxam provide better control and protection against crucifer flea beetles than striped flea beetles. The authors suggested that differences in efficacy of neonicotinoid seed treatments to the two species could shift their geographic distribution and economic importance.

In recent years, producers in western Canada have reported so-called 'seed treatment failures' against flea beetles in canola. In response to these reports, growth chamber experiments funded by the Canola Clusters program were initiated to identify potential factors that could be causing these failures. Lab bioassays focused on the effect of moisture conditions and temperature on the efficacy of neonicotinoid seed treatments against crucifer and striped flea beetles. In the bioassays, neonicotinoid seed treatments were more effective against flea beetles in dry soil than in wet soil and more effective at 20ºC and 30ºC than at 10ºC. More importantly, neonicotinoid seed treatments provided substantially better control and protection against crucifer flea beetles than striped flea beetles. Control and protection against striped flea beetles was poorest in wet soil at low temperatures. To address this problem, collaborative studies were initiated with several chemical companies in 2011 to evaluate the efficacy of new chemistries and seed treatment formulations for control of striped and crucifer flea beetles. Bioassays were done in dry and wet soil at 10, 20 and 30ºC. The objectives of the bioassays were to identify seed treatments that provide the best flea beetle control, best protection against feeding damage and greatest improvement in seedling growth. Results were sent to the chemical companies and forwarded to PMRA to support the registration of the most efficacious seed treatments. Over the past 18 months, two diamide seed treatments (Lumiderm and Fortenza) and three diamide/neonicotinoid mixtures (Lumiderm/Prosper, Lumiderm/Helix XTra and Fortenza/Helix XTra) have been registered for control of flea beetles in Canada. Two additional seed treatments (EX 1 and EX 2) are currently under review by PMRA. After the final report was submitted, EX 1 and EX 2 were registered for control of flea beetles in canola in Canada. EX 1 containing the sulfoximide insecticide, sulfoxaflor, was registered under the trade name Rascendo. EX 2 containing a mixture of Helix XTra and Rascendo was registered under the trade name Visivio.

With funding from SaskCanola and private industry, field trials were conducted in 2013-2015 to evaluate seed treatments for control of leafhoppers and flea beetles in different canola types. As described in previous sections of the final report, leafhopper populations and incidence of AY were very low in 2013, 2014 and 2015. In contrast, populations of crucifer and/or striped flea beetles were moderate to very high. Therefore, the primary objectives of the field trials were to evaluate the effect of seed treatments on flea beetle damage and agronomic performance including stand establishment, shoot growth and seed yield.

EXPERIMENTAL METHODS

Flea beetle collection and rearing

Flea beetles were collected from commercial fields near Saskatoon in the spring of 2011 and 2012. Striped flea beetles were collected in late April and early May from fields where canola was grown the previous year. Beetles were collected with sweep nets from volunteer canola seedlings that germinated along swaths. Crucifer flea beetles were collected in late May and June from volunteer canola and flix weed *Descurania sophia* (L.) in non-crop areas. Adults of each species were aspirated into vials and placed in mesh cages in a growth chamber. Beetles were reared on canola and cabbage leaves (*Brassica oleracea* var. *capitata*) at 20/15°C and corresponding 16h light/8h dark photoperiod for at least one week before testing.

Laboratory bioassays

In bioassays on each flea beetle species, we evaluated 10 treatments at three temperatures (10, 20 and 30°C) and two moisture regimes (dry and wet). Assays on striped flea beetles were conducted in May and early June; those on crucifer flea beetles in June and early July. In 2011, we evaluated 10 treatments including untreated bare seed, a fungicide check treatment (Tribune), four neonicotinoid seed treatments (Gaucho CS FL - 400 g imidacloprid/100 kg seed; Prosper FX - 400 g clothianidin/100 kg seed; Helix - 200 g thiamethoxam/100 kg seed and Helix XTra - 400 g thiamethoxam/100 kg seed), two diamide seed treatments (Lumiderm - 1000 g cyantraniliprole/100 kg seed and Fortenza - 800 g cyantraniliprole/100 kg seed), one diamide/neonicotinoid mixture(Lumiderm plus Prosper) and one experimental seed treatment (EX 1). In 2012, we evaluated 10 treatments including untreated bare seed, a fungicide check treatment (Tribune), four neonicotinoid seed treatments (Gaucho CS FL - 400 g imidacloprid/100 kg seed; Prosper FX - 400 g clothianidin/100 kg seed; Helix - 200 g thiamethoxam/100 kg seed and Helix XTra - 400 g thiamethoxam/100 kg seed), one diamide seed treatment (Fortenza - 800 g cyantraniliprole/100 kg seed), one seed treatment mixture (Fortenza plus Helix XTra) and two experimental seed treatments (EX 1 and EX 2). The treatments were applied to seeds of Roundup Ready hybrid canola with a Wintersteiger Hege II seed-treater. Each treatment was applied at the rate recommended by the manufacturer to a 60 g seed sample at 3600 rpm for 30 seconds.

To assess the effect of soil moisture on efficacy, bare and treated seeds were planted individually in plastic cones (49 ml capacity; Stuewe and Sons, Tangent, OR) containing an artificial medium (Stringam 1971). The medium was compacted and seeds planted at a 15 mm depth. Cones were placed in polystyrene trays (n = 200 cones/tray;

Stuewe and Sons) in a controlled environment chamber set at 20°C/15°C, corresponding 16L/8D photoperiod and 100-140 µmol/m^2/s^1 light intensity. By adjusting the daily watering regime, seeds from each treatment were grown in ‘dry medium’ (2 ml water/cone/day; 20-30% moisture content on dry weight basis) and ‘wet medium’ (6 ml water/cone/day; 70-100% moisture content).

Seedlings at the cotyledon stage were transferred into vented acrylic cages (15x15x15 cm) mounted on polystyrene trays (n = 2 cages/tray). Each cage contained two rows of five seedlings from a particular treatment that were grown in either dry or wet medium. Trays with the 10 treatments and two moisture regimes were placed in a controlled environment chamber (Conviron, model PGV35) set at 10, 20 or 30°C, 50-60% relative humidity, 16h light/8h dark photoperiod and 400 µmol/m^2/s^1 light intensity. Twenty flea beetles that had been starved for 16-18 h were added to each cage. Seedlings were watered daily to maintain dry or wet conditions throughout the bioassay. Bioassays on each flea beetle species were replicated four times using a randomized split-split plot design with temperatures as main plots, treatments as subplots and soil moisture as sub-subplots.

Flea beetle damage to the cotyledons of each seedling was assessed after 24 h and 72 h using a 0- to 10-point scale than corresponded to the percentage of the cotyledon surface that was eaten by flea beetles (Palaniswamy et al. 1992; Elliott et al. 2008). Based on the scale, a rating of 0.5, 1.0 and 2.0 was assigned when 5, 10 and 20% of the cotyledon surface was eaten. After 72 h, live and dead beetles were aspirated into vials and counted. Moribund beetles were placed in water to ascertain if there was any movement. Canola seedlings were harvested at ground level and weighed to determine the shoot fresh weight. Samples were dried at 60°C for 3-7 days and weighed to determine dry matter content.

Field tests 2013-2015

Field tests were conducted in annually at the AAFC Research Farm. Plots were fertilized the previous fall or early May with an N/P/S fertilizer blend (90-120, 40-45 and 28-35 kg/ha, respectively) based on soil-test recommendations for canola production. Plots were also treated with trifluralin (Advance 10G).

Meteorological data including daily air temperatures and precipitation were obtained from Environment Canada. Soil temperature at 5-cm depth was monitored hourly with an Onset Tidbit v2 temperature data logger (Hoskin Scientific). Soil moisture was monitored weekly using a Theta Probe soil moisture sensor (Type ML2X).

Tests were conducted on Roundup Ready (RR) hybrid canola, Clearfield (CL) hybrid canola and canola mustard. Depending on the year, we evaluated 10-13 treatments including untreated bare seed, a fungicide check treatment (Tribune), four neonicotinoid seed treatments (Gaucho CS FL - 400 g imidacloprid/100 kg seed; Prosper Evergol - 400 g clothianidin/100 kg seed; Helix - 200 g thiamethoxam/100 kg seed and Helix XTra - 400 g thiamethoxam/100 kg seed), two diamide seed treatments (Lumiderm - 1000 g cyantraniliprole/100 kg seed and/or Fortenza - 800 g cyantraniliprole/100 kg seed), four diamide/neonicotinoid mixtures (Lumiderm/Prosper; Lumiderm/Helix XTra; Fortenza/Helix XTra and/or Fortenza/Helix) and two experimental seed treatments (EX 1 and EX 2). Seed treatments were applied to seeds of each canola type with a Wintersteiger Hege seed-treater at 3600 rpm for 30 seconds.

Untreated and treated seeds were planted in six-row plots at 200 seeds per 6.1 m row (1.5-2.0 cm depth; 0.30 row-spacing) with a Hege multiple cone double-disc seeder equipped with on-row packers. Each test was replicated four times using a randomized complete block design. Tests on canola mustard, RR hybrid canola and CL hybrid canola were planted May 17-23 in 2013, May 12-15 in 2014 and May 13-20 in 2015. Untreated seeds of each canola type were planted adjacent to each test. Yellow sticky cards (12.8 cm x 15.2 cm; Alpha Scents Inc.) were placed in the plots at weekly intervals throughout the growing season. Cards were examined under a microscope to determine numbers of crucifer flea beetles, striped flea beetles, hop flea beetles and aster leafhoppers present.

To evaluate flea beetle protection from the seed treatments, feeding damage to the cotyledons (n = 20 cotyledons/plot) was assessed 14, 18 and 21 days after seeding (DAS). Damage was assessed visually using a 0- to 10-point scale that corresponded to the percentage of the cotyledon surface that was eaten by flea beetles (Elliott et al. 2007). To assess the effect of the seed treatments on seedling emergence and stand establishment, numbers of seedlings along a centre row of each plot were counted 14, 21 and 28 DAS. All plots were planted at 200 seeds per row so seedling counts were converted to % emergence or % establishment. To assess the effect of the seed treatments on vigor and shoot growth, 10 plants were collected from the outer rows of each plot 14, 21 and 28 DAS. Samples were placed in plastic bags and transported to the lab in coolers. Shoots were cleaned and weighed to determine fresh weight. Samples were dried at 60°C for 3-7 days and weighed to determine dry matter content. Shoot biomass, expressed as g/m-row, was calculated from the number of seedlings per m-row and shoot fresh weights 14, 21 and 28 DAS. Plots were inspected for evidence of AY symptoms in late August. The four centre rows of each plot were swathed and harvested at maturity with a small-plot combine. Samples were cleaned, dried and weighed to estimate seed yield.

Statistical analyses

Statistical analyses were done using the General Linear Model procedure (SAS institute, 1999). Variance and normality were evaluated using the Univariate procedure and Shapiro-Wilk statistic. To stabilize the variance and normalize the distribution, percentage values pertaining to flea beetle mortality and feeding damage were transformed using the arcsine square root function before analysis of variance (ANOVA). Data were analyzed as a factorial split-split plot design with temperatures as main plots, seed treatments as subplots and moisture regimes as sub subplots. As described in the Results, statistical interactions (seed treatment, temperature and/or moisture) were significant ($P \leq 0.05$) on most variables in each flea beetle species so treatment data from each temperature and moisture regime were analyzed separately. Treatment means were compared using the Waller-Duncan k-ratio test ($k = 100$; $P = 0.05$). Spearman-rank and Pearson correlations were conducted on seed treatment data from lab and field tests to assess the association between flea beetle mortality, feeding damage and seedling weight.

RESULTS AND CONCLUSIONS

Flea beetle bioassays 2011

In bioassays on crucifer and striped flea beetles in 2011, temperature had a significant effect ($F = 11.3\text{-}117.1$; df = 2, 6; $P \leq 0.01\text{-}0.001$) on flea beetle mortality, flea beetle feeding damage and seedling fresh weight (Table 1). In each species, mortality and feeding damage after 24 and 72 h were lowest at 10ºC and highest at 30ºC. In assays on *P. cruciferae*, seedling weights were lower at 10ºC than at 20ºC or 30ºC. In assays on *P. striolata*, seedling weights were lowest at 30ºC and highest at 20ºC. Seed treatments had a significant effect ($F = 12.3\text{-}101.5$; df = 9, 81; $P \leq 0.001$) on flea beetle mortality, feeding damage and seedling weight. In each species, seedlings grown from untreated seeds and Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling weight. In bioassays on *P. cruciferae*, seedlings grown from seeds treated with Helix XTra or the Lumiderm/Prosper mixture had the highest flea beetle mortality. Seedlings grown from seeds treated with Prosper FX, Helix XTra or Lumiderm/Prosper mixture had the lowest feeding damage after 24 and 72 h. Seedlings grown from seeds treated with Prosper FX, Helix XTra, Fortenza, Lumiderm or Lumiderm/Prosper mixture had the highest fresh weight. In bioassays on *P. striolata*, seedlings grown from seeds treated with Gaucho CS FL, Prosper FX, Helix XTra, Fortenza, Lumiderm or Lumiderm/Prosper mixture had the highest flea beetle mortality. Seedlings grown from seeds treated with Gaucho CS FL, Prosper FX, Fortenza, EX 1, Lumiderm or Lumiderm/Prosper mixture had the lowest feeding damage after 24 h. Seedlings grown from seeds treated with EX 1 had the lowest feeding damage after 72 h and highest fresh weight. However, the temperature by seed treatment interaction on all variables was significant ($F = 3.1\text{-}24.7$; df = 18, 81; $F = P \leq 0.001$) in each species. Soil moisture also had a significant effect ($F = 65.6\text{-}94.5$, 1, 90; $F = P = 0.01\text{-}0.001$) on mortality of each flea beetle species. Mortality was higher in dry soil than in wet soil. Moisture had no effect on feeding damage by *P. cruciferae*. In contrast, damage by *P. striolata* was higher in wet soil than in dry soil. In assays on each species, seedling weights were higher in wet soil than in dry soil. Two-way and/or three-way interactions on mortality (M x T; M x ST) and feeding damage (M x ST; M x T x ST) were significant in bioassays on each species so seed treatment data from each temperature and moisture regime were analyzed separately.

Seed treatments had a significant effect ($F = 7.3\text{-}33.5$; df = 9, 27; $P \leq 0.001$) on mortality of *P. cruciferae* at each temperature and moisture regime (Fig. 1). Mortality in wet and dry soil at 10, 20 and 30ºC was lowest on seedlings grown from bare seeds (0-5% mortality) and seeds treated with Tribune (1-5% mortality). At 10ºC, Helix, Prosper FX, Helix XTra, Lumiderm and Lumiderm/Prosper mixture provided the best flea beetle control in wet soil (22-28%mortality). Prosper FX, Helix XTra and Lumiderm/Prosper mixture provided the best control in dry soil (45-58% mortality). At 20ºC, the Lumiderm/Prosper mixture, followed by Helix, Prosper FX, Helix XTra and Lumiderm provided the best control in wet soil (42-61% mortality). Prosper FX, Helix XTra and Lumiderm/Prosper mixture provided the best control in dry soil (75-86% mortality). At 30ºC, Helix, Prosper FX, Helix XTra and Lumiderm/Prosper mixture provided the best control in wet soil (66-84% mortality) whereas Helix, Helix XTra and Lumiderm/Prosper mixture provided the best control in dry soil (88-96% mortality).

Seed treatments had a significant effect ($F = 3.3\text{-}37.2$; df = 9, 27; $P \leq 0.01$) on feeding damage by crucifer flea beetles after 24 h at each temperature and moisture regime (Fig. 2). At 10ºC, damage in the check treatments averaged 4-5% in wet soil and 3-4% in dry soil. All remaining treatments except EX 1 reduced damage to 2.6-3.1% in wet soil. Prosper FX and Helix XTra provided the best flea beetle protection in dry soil, reducing damage to 2.3-2.4%. At 20ºC, damage in the check treatments averaged 7-8% in wet and dry soil. Prosper FX and Helix XTra provided the best protection in wet soil (3.3-3.5% damage) whereas Gaucho, Helix, Prosper FX and the Lumiderm/Prosper mixture provided the best protection (3.0-3.3% damage) in dry soil. At 30ºC, damage in the check treatments averaged 15-16% in wet soil and 18-21% in dry soil. All remaining treatments except EX 1 reduced damage to 4-5% in wet soil. Prosper FX, Helix XTra, Fortenza, Lumiderm and the Lumiderm/Prosper mixture provided the best protection (3.9-4.8% damage) in dry soil.

Seed treatments had a significant effect ($F = 2.9\text{-}74.2$; df = 9, 27; $P \leq 0.05$) on feeding damage by crucifer flea beetles after 72 h at each temperature and moisture regime (Fig. 3). At 10ºC, damage in the check treatments averaged 5-6% in wet and dry soil. All remaining treatments except EX 1 and Lumiderm reduced damage to 3.0-3.7% in wet soil and 3.1-3.7% in dry soil. At 20ºC, damage in the check treatments averaged 13-15% in wet and dry soil. Prosper FX and the Lumiderm/Prosper mixture provided the best protection (3.9-4.1% damage) in wet soil. Gaucho CS FL, Helix, Prosper FX, Helix XTra and the Lumiderm/Prosper mixture provided the best protection (3.6-4.2% damage) in dry soil. At 30ºC, damage in the check treatments averaged 28-29% in wet soil and 35-45% in dry soil. Prosper FX, Helix XTra, Lumiderm and the Lumiderm/Prosper mixture provided the best protection (4.6-5.6% damage) in wet soil. Helix XTra, the Lumiderm/Prosper mixture followed by Gaucho, Helix and Prosper FX provided the best protection (4.6-6.6% damage) in dry soil at 30ºC.

Seed treatments had little or no effect ($F = 1.5\text{-}1.6$; df = 9, 27; $P \geq 0.05$) on the fresh weight of canola seedlings exposed to crucifer flea beetles in dry and wet soil at 10ºC (Fig. 4). At 20ºC, seedlings grown from seeds treated with Lumiderm or Lumiderm/Prosper mixture had the highest fresh weight in wet soil (277-282 mg) and dry soil (191-198 mg). Compared to Tribune, the treatments improved fresh weight by 22-24% in wet soil and by 25-29% in dry soil. In wet soil at 30ºC, plants grown from seeds treated with Prosper FX, Fortenza or Lumiderm/Prosper mixture had the highest fresh weight (291-304 mg) and improved fresh weight by 57-64% compared to Tribune. In dry soil at 30ºC, all treatments except EX 1 improved fresh weight by 90-120% compared to Tribune.

Seed treatments had little or no effect ($F = 0.7\text{-}2.2$; df = 9, 27; $P \geq 0.05$) on the dry weight of canola seedlings exposed to crucifer flea beetles in dry and wet soil at 10ºC and 20ºC (Fig. 5). At 30ºC, seedlings grown from seeds treated with Prosper FX, Helix XTra, Fortenza and Lumiderm/Prosper mixture had the highest weight in wet soil (20.9-23.2 mg) and improved dry matter by 34-48% compared to Tribune. Plants grown from seeds treated with Helix or Fortenza had the highest dry weight in dry soil (15.6-16.4 mg) and improved dry matter by 66-74% compared to Tribune.

Seed treatments were ranked on their ability to control crucifer flea beetles, reduce feeding damage after 24 and 72 h and improve seedling fresh weight (Table 2). Based on these four criteria, the Lumiderm/Prosper mixture, Prosper FX, Helix XTra and Fortenza had the highest overall rankings (1-4, respectively) in bioassays conducted in wet soil. Helix XTra, Lumiderm/Prosper mixture, Helix and Prosper FX had the highest rankings in bioassays conducted in dry soil.

Seed treatments had a significant effect ($F = 2.5\text{-}9.8$; df = 9, 27; $P \leq 0.05$) on mortality of *P. striolata* at most temperatures and moisture regimes (Fig. 6). Mortality in wet and dry soil at 10, 20 and 30ºC was lowest (1-4% mortality) on seedlings grown from bare seeds and seeds treated with Tribune. At 10ºC, Helix, Prosper FX, Helix XTra, Fortenza, EX 1 and Lumiderm/Prosper mixture provided the best flea beetle control (7-9%mortality) in wet soil. EX 1 provided the best control (29% mortality) in dry soil. All treatments provided poor control of *P. striolata* (3-10% mortality) in wet soil at 20ºC. EX 1, Helix XTra and Fortenza provided the best control (15-24% mortality) in in dry soil at 20ºC. EX 1, Fortenza, Lumiderm and Lumiderm/Prosper mixture provided the best control (20-28% mortality) in wet soil at 30ºC. Helix XTra and EX 1 provided the best control (47-64%mortality) in dry soil at 30ºC.

Seed treatments had a significant effect ($F = 2.4\text{-}15.5$; df = 9, 27; $P \leq 0.05$) on feeding damage by striped flea beetles after 24 h at most temperatures and moisture regimes (Fig. 7). Damage in the check treatments averaged 3-4% in wet and dry soil at 10ºC. Lumiderm, Helix and Prosper FX provided the best protection (2-3% damage) against feeding damage in wet soil. All treatments had no effect on damage in dry soil at 10ºC. Damage in the check treatments averaged 6-11% in wet and dry soil at 20ºC. Most treatments except Helix reduced damage to 4-7% in wet soil at 20ºC. Gaucho CS FL, Prosper FX, Helix XTra, Fortenza, EX 1 and Lumiderm/Prosper mixture reduced damage to 3-5% in dry soil at 20ºC. Damage in check treatments at 30ºC averaged 24-33% in wet soil and 34-39% in dry soil. Gaucho CS FL, Prosper FX, Fortenza, EX 1, Lumiderm and Lumiderm/Prosper mixture reduced damage to 9-13% in wet soil. Gaucho CS FL, Prosper FX, Helix XTra, EX 1 and Lumiderm reduced damage to 4-8% in dry soil.

Seed treatments had a significant effect ($F = 2.4\text{-}14.1$; df = 9, 27; $P = 0.05\text{-}0.001$) on feeding damage by striped flea beetles after 72 h at most temperatures and moisture conditions (Fig. 8). Feeding damage in the check treatments at 10ºC averaged 5% in wet soil and 5-7% in dry soil. Treatments had no effect on damage in wet soil. Gaucho CS FL, Prosper FX, Helix XTra, Fortenza, EX 1 and Lumiderm/Prosper mixture provided the best protection against feeding damage (3-4% damage) in dry soil at 10ºC. Damage in the check treatments at 20ºC averaged 17-23% in wet soil and 22-27% in dry soil. Fortenza, EX 1 and Lumiderm/Prosper mixture provided the best protection (9-13% damage) in wet soil. Gaucho CS FL, Helix XTra, Fortenza, EX 1 and Lumiderm/Prosper mixture provided the best protection (6-12% damage) in dry soil. Damage in the check treatments at 30ºC averaged 50-60% in wet soil and 60-75% in dry soil. Prosper FX, Helix XTra, Fortenza, EX 1 and Lumiderm/Prosper mixture provided the best protection (21-34% damage) in wet soil. Prosper FX, Helix XTra, EX 1 and Lumiderm/Prosper mixture provided the best protection (8-20% damage) in dry soil.

In most instances, seed treatments had a significant effect ($F = 3.9\text{-}11.2$; df = 9, 27; $P \leq 0.01$) on the fresh weight of canola seedlings exposed to striped flea beetles (Fig. 9). Seedlings grown from seeds treated with Helix, Fortenza or Lumiderm had the highest fresh weight (157-168 mg) in wet soil at 10ºC. Treatments had no effect on seedling fresh weight in dry soil at 10ºC. At 20ºC, seedlings grown from seeds treated with Fortenza, EX 1 and Lumiderm/Prosper mixture had the highest fresh weight in wet soil (187-211 mg) and dry soil (121-140 mg). Compared to Tribune, the treatments improved fresh weight by 25-45% in wet and dry soil. Seedlings grown from seeds treated with EX 1, Lumiderm or Lumiderm/Prosper mixture had the highest fresh weight (133-174 mg) in wet soil at 30ºC. Seedlings grown from seeds treated with EX 1 or Helix XTra had the highest fresh weight (107-131 mg) in dry soil at 30ºC. Compared to Tribune, the treatments improved fresh weight by 69-105% in wet soil and by 150-205% in dry soil.

Seed treatments had little or no effect ($F = 0.9\text{-}2.2$; df = 9, 27; $P \geq 0.05$) on the dry weight of canola seedlings exposed to striped flea beetles at 10ºC and 20ºC (Fig. 10). Seedlings grown from seeds treated with Helix, Fortenza or Lumiderm had the highest dry weight (8.9-9.7 mg) in wet soil at 10ºC. At 20ºC, seedlings grown from seeds treated with Fortenza had the highest dry weight in wet soil (12.4 mg) and in dry soil (9.7 mg). Compared to Tribune, Fortenza improved dry matter by 30% in wet soil and by 22% in dry soil. Seedlings grown from seeds treated with EX 1 or Lumiderm had the highest dry weight (10.3-10.7 mg) in wet soil at 30ºC. Seedlings grown from seeds treated with EX 1 had the highest dry weight in dry soil at 30ºC. Compared to Tribune, the treatments improved dry matter by 27-32% in wet soil and by 34% in dry soil.

Seed treatments were ranked on their ability to control striped flea beetles, reduce feeding damage after 24 and 72 h and improve seedling fresh weight (Table 3). Based on these criteria, Fortenza, EX 1, Lumiderm/Prosper mixture and Lumiderm had the highest overall rankings in bioassays on striped flea beetles in wet soil. EX 1, Helix XTra, Lumiderm/Prosper mixture, Prosper FX and Fortenza had the highest rankings in bioassays on striped flea beetles in dry soil.

Flea beetle mortality in the seed treatments at different temperatures and moisture conditions were correlated with feeding damage and fresh/dry weight of the seedlings (Table 4). In bioassays on *P. cruciferae*, flea beetle mortality was negatively correlated (-r = 0.42-0.80; P = 0.01-0.001) with feeding damage after 24, 48 and 72 h in wet and dry soil at 10, 20 and 30ºC. Mortality was positively correlated (r = 0.52-0.73; $P \leq 0.001$) with fresh weight and dry weight in wet and dry soil at 30ºC. In bioassays on *P. striolata*, flea beetle mortality was negatively correlated (-r = 0.48-0.70; P = 0.01- 0.001) with feeding damage after 24, 48 and 72 h in dry soil at 20ºC and 30ºC but poorly correlated (-r = 0.00-0.23; $P \geq 0.05$) with feeding damage in wet soil at 10, 20 and 30ºC. Mortality was positively correlated (r = 0.40-0.66; P = 0.01-0.001) with seedling fresh and dry weight in dry soil at 30ºC but poorly correlated with seedling weights at other conditions.

Flea beetle bioassays 2012

In bioassays on crucifer and striped flea beetles in 2012, temperature had a significant effect (F = 7.6-196.6; df = 2, 6; P = 0.05-0.001) on flea beetle mortality, flea beetle feeding damage and seedling fresh weight (Table 5). In each species, mortality and feeding damage after 24 and 72 h were lowest at 10ºC and highest at 30ºC. In assays on *P. cruciferae*, seedling weights were lower at 10ºC than at 20ºC or 30ºC. In assays on *P. striolata*, seedling weights were lower at 10ºC and 30ºC than at 20ºC. Seed treatments had a significant effect (F = 17.7-135.1; df = 9, 81; $P \leq 0.001$) on flea beetle mortality, feeding damage and seedling weight. In each species, seedlings grown from untreated or Tribune-treated seeds had the lowest flea beetle mortality, highest feeding damage and lowest seedling weight. In bioassays on *P. cruciferae*, seedlings grown from seeds treated with Helix XTra, Fortenza/Helix XTra mixture, EX 2 or Prosper FX had the highest flea beetle mortality, lowest feeding damage and highest seedling weight. In bioassays on *P. striolata*, seedlings grown from seeds treated with EX 1 or Fortenza/Helix XTra mixture had the highest flea beetle mortality. Seedlings grown from seeds treated with EX 1, EX 2, Prosper FX or Fortenza/Helix XTra mixture had the lowest feeding damage after 24 h, lowest feeding damage after 72 h and highest seedling weight. However, the temperature by seed treatment interaction on all variables was significant ($F = 3.2$-15.9; df = 18, 81; $P \leq 0.001$) in each species. Soil moisture also had a significant effect ($F = 8.5$-1895.0; df = 1, 90; $P = 0.01$-0.001) on most variables in each flea beetle species. Mortality was higher in dry soil than in wet soil. Conversely, feeding damage after 24 h and fresh weight were higher in wet soil than in dry soil. Two-way and three-way interactions on mortality (M x ST; M x T x ST) and feeding damage (M x ST; M x T x ST) were significant in each flea beetle species so seed treatment data from each temperature and moisture condition were analyzed separately.

Seed treatments had a significant effect ($F = 6.1$-61.0; df = 9, 27; $P \leq 0.001$) on mortality of *P. cruciferae* at each temperature and moisture regime (Fig. 11). Mortality in wet and dry soil at 10, 20 and 30ºC was lowest on seedlings grown from bare seeds (0-4% mortality) and seeds treated with Tribune (2-5% mortality). At 10ºC, Prosper FX, Helix XTra, Fortenza, EX 2 and Fortenza/Helix XTra mixture provided the best flea beetle control in wet soil (20-25% mortality). Prosper FX, Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best control in dry soil (41-56% mortality). At 20ºC, Prosper FX, Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best control in in wet soil (47-59% mortality). Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best control in dry soil (77-84% mortality). At 30ºC, Prosper FX, Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best control in wet soil (78-86% mortality) and dry soil (93-97% mortality).

Seed treatments had a significant effect ($F = 4.0$-52.8; df = 9, 27; $P = 0.01$-0.001) on feeding damage by crucifer flea beetles after 24 h at each temperature and moisture regime (Fig. 12). At 10ºC, damage in the check treatments averaged 3-4% in wet and dry soil. Prosper FX, Helix XTra and EX 2 reduced damage to 2.1-2.4% in wet soil. Helix, EX 2 and Fortenza/Helix XTra mixture provided the best flea beetle protection in dry soil, reducing damage to 1.9-2.3%. At 20ºC, damage in the check treatments averaged 5-7% in wet and dry soil. All treatments except EX 1 provided adequate protection in wet soil (2.9-3.3% damage) and dry soil (2.4-3.1% damage). At 30ºC, damage in the check treatments averaged 11-12% in wet soil and 14-17% in dry soil. All treatments except EX 1 reduced damage to 3.1-4.4% in wet soil and 2.3-3.3% in dry soil.

Seed treatments had a significant effect ($F = 5.7$-82.1; df = 9, 27; $P \leq 0.001$) on feeding damage by crucifer flea beetles after 72 h at each temperature and moisture regime (Fig. 13). At 10ºC, damage in the check treatments averaged 4-5% in wet and dry soil. Prosper FX, Helix XTra, Fortenza, EX 2 and Fortenza/Helix XTra mixture reduced damage to 2.8-3.3% in wet soil. Helix XTra, EX 2 and the Fortenza/Helix XTra mixture reduced damage to 2.6-2.9% in dry soil. At 20ºC, damage in the check treatments averaged 10-12% in wet and dry soil. Helix, Prosper FX, Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best protection in wet soil (3.8-4.3% damage) and dry soil (3.3-3.9% damage). At 30ºC, damage in the check treatments averaged 22-25% in wet soil and 38-51% in dry soil. Prosper FX, Helix XTra, EX 2 and Fortenza/Helix XTra mixture provided the best protection (4.5-5.9% damage) in wet soil. All treatments except EX 1 provided excellent protection (3.9-5.8% damage) in dry soil.

Seed treatments had no effect ($F = 0.2$; df = 9, 27; $P \geq 0.05$) on the fresh weight of canola seedlings exposed to crucifer flea beetles in wet soil at 10ºC (Fig. 14). At 20ºC, seedlings grown from seeds treated with Helix, Helix XTra, EX 2 and Fortenza/Helix XTra mixture had the highest fresh weight (306-318 mg) in wet soil. Seedlings grown from seeds treated with Helix or EX 2 had the highest fresh weight (205-215 mg) in dry soil. Compared to Tribune, the treatments improved fresh weight by 16-20% in wet soil and by 32-38% in dry soil. In wet soil at 30ºC, plants grown from seeds treated with Prosper FX, Helix XTra, Fortenza, EX 2 or Fortenza/Helix XTra mixture had the highest fresh weight (307-326mg) and improved fresh weight by 25-33% compared to Tribune. In dry soil at 30ºC, all treatments except EX 1 improved fresh weight by 110-130% compared to Tribune.

Seed treatments had no effect ($F = 0.3-2.1$; $df = 9, 27$; $P \geq 0.05$) on the dry weight of canola seedlings exposed to crucifer flea beetles in dry and wet soil at 10ºC (Fig. 15**).** At 20ºC, seedlings grown from seeds treated with Helix, Helix XTra or EX 2 had the highest weight in wet soil (16.1-16.8 mg) and dry soil (11.7-12.8 mg). Compared to Tribune, the treatments improved dry matter by 4-9% in dry soil and by 8-18% in wet soil. At 30ºC**,** seedlings grown from seeds treated with Helix, Prosper FX, Helix XTra, EX 2 or Fortenza/Helix XTra mixture had the highest dry weight in wet soil (21.0-22.7 mg) and improved dry matter by 9-14% compared to Tribune. Plants grown from seeds treated with Helix or Fortenza had the highest weight in dry soil (12.7-13.5 mg) and improved dry matter by 9-14% compared to Tribune. All treatments except EX 1 improved dry weights in wet soil by 30-40% compared to Tribune.

Seed treatments were ranked on their ability to control crucifer flea beetles, reduce feeding damage after 24 and 72 h and improve seedling fresh weight (Table 6). EX 2, the Fortenza/Helix XTra mixture, Prosper FX and Helix XTra had the highest overall rankings in bioassays on crucifer flea beetles in wet soil. Helix XTra, EX 2, Fortenza/Helix XTra mixture and Helix had the highest rankings in bioassays on crucifer flea beetles in dry soil.

Seed treatments had no effect ($F = 0.8-2.1$; $df = 9, 27$; $P \geq 0.05$) on mortality of striped flea beetles in wet soil at 10, 20 and 30ºC (Fig. 16). EX 1, EX 2 and Fortenza/Helix XTra mixture provided the best flea beetle control (21-23% mortality) in dry soil at 20ºC. Fortenza and the Fortenza/Helix XTra mixture provided the best control (13-14% mortality) in wet soil at 30ºC. EX 1 and the Fortenza/Helix XTra mixture provided the best control (73-81% mortality) in dry soil at 30ºC.

Seed treatments had a significant effect ($F = 2.5-41.3$; $df = 9, 27$; $P = 0.05-0.001$) on feeding damage by striped flea beetles after 24 h at each temperature and moisture regime (Fig. 17). The Fortenza/Helix XTra mixture provided the best protection (2.9% damage) against feeding damage in wet soil. EX 1 and EX 2 provided the best protection (2.3-2.4% damage) in dry soil. Damage in the check treatments averaged 7-8% in wet and dry soil at 20ºC. Fortenza provided the best protection (4.4% damage) in wet soil. EX 1 and EX 2 provided the best protection (3.8-4.1% damage) in dry soil. Damage in the check treatments at 30ºC averaged 20-22% in wet soil and 28-30% dry soil. Fortenza, EX 2 and the Fortenza/Helix XTra mixture provided the best protection (6.2-7.6% damage) in wet soil. All treatments except Fortenza provided satisfactory protection (4.6-8.6% damage) in dry soil.

Seed treatments had a significant effect ($F = 3.0-18.0$; $df = 9, 27$; $P = 0.05-0.001$) on feeding damage by striped flea beetles after 72 h at most temperatures and moisture regimes (Fig. 18). Damage in the check treatments averaged 6-7% in wet and dry soil at 10ºC. Seedlings grown from seeds treated with Fortenza, EX 1, EX 2 or Fortenza/Helix XTra mixture had the lowest damage in wet soil (4.8-5.2% damage) and dry soil (4.3-4.6% damage). Damage in the check treatments at 20ºC averaged 12-14% in wet soil and 21-22% in dry soil. Fortenza, EX 2 and the Fortenza/Helix XTra mixture provided the best protection (7.0-9.8% damage) in wet soil. Prosper FX, EX 1, EX 2 and the Fortenza/Helix XTra mixture provided the best protection (5.9-7.9% damage) in dry soil. Damage in the check treatments at 30ºC averaged 30-35% in wet soil and 62-66% in dry soil. Fortenza, EX 2 and the Fortenza/Helix XTra mixture provided the best protection (14-16% damage) in wet soil. EX 1, EX 2 and the Fortenza/Helix XTra mixture provided the best protection (7-8% damage) in dry soil.

Seed treatments had a significant effect on the fresh weight of canola seedlings exposed to striped flea beetles in wet soil at 30ºC ($F = 5.9$; $df = 9, 27$; $P \leq 0.001$) and dry soil at 10, 20 and 30ºC ($F = 3.1$-19.1; $df = 9, 27$; $P = 0.05$-0.001) (Fig. 19). Seedlings grown from untreated seeds or seeds treated with Tribune had the lowest weights at most conditions. At 10ºC, seedlings grown from seeds treated with the Fortenza/Helix XTra mixture the highest fresh weight (224 mg) in wet soil. Seedlings grown from seeds treated with EX 2 had the highest weight (137 mg) in dry soil. Compared to Tribune, the treatments improved fresh weight by 10% in wet soil and by 24% in dry soil**.** At 20ºC, seedlings grown from seeds treated with Fortenza/Helix XTra mixture had the highest fresh weight in wet soil (274 mg). Seedlings grown from seeds treated with Prosper FX, EX 1, EX 2 or Fortenza/Helix XTra mixture had the highest weight (148-165 mg) in dry soil. Compared to Tribune, the treatments improved fresh weight by 8% in wet soil and by 24-35% in dry soil. At 30ºC, seedlings grown from seeds treated with EX 2 had the highest fresh weight (306 mg) in wet soil. Seedlings grown from seeds treated with EX 1 or EX 2 had the highest fresh weight (106-123 mg) in dry soil. Compared to Tribune, the treatments improved fresh weight by 45% in wet soil and by 220-270% in dry soil.

Seed treatments had a significant effect on the dry weight of canola seedlings exposed to striped flea beetles in wet soil at 30ºC ($F = 5.7$; $df = 9, 27$; $P \leq 0.001$) and dry soil at 10, 20 and 30ºC ($F = 32.6$-5.3; $df = 9, 27$; P 0.05-0.001) (Fig. 20). At 10ºC, seedlings grown from seeds treated with the Fortenza/Helix XTra mixture had the highest dry weight (13.3 mg) in wet soil. Seedlings grown from seeds treated with Helix or EX 1 had the highest dry weight (9.1 mg) in dry soil. At 20ºC, seedlings grown from seeds treated EX 2 or the Fortenza/Helix XTra mixture had the highest dry weight (10.8 mg) in dry soil. Compared to Tribune, the treatments improved dry matter by 20%. At 30ºC, seedlings grown from seeds treated with EX 2 had the highest dry weight (27.7 mg) in wet soil at 30ºC. Seedlings grown from seeds treated with Helix XTra, EX 1, EX 2 or Fortenza/Helix XTra mixture had the highest weights (10.8-12.1 mg) in dry soil. Compared to Tribune, the treatments improved dry matter by 40% in wet soil and by 32-48% in dry soil.

Seed treatments were ranked on their ability to control striped flea beetles, reduce feeding damage after 24 and 72 h and improve seedling fresh weight (Table 7). The Fortenza/Helix XTra mixture, Fortenza, EX 2 and EX 1 ranked highest in bioassays on striped flea beetles in wet soil. EX 1, EX 2, Fortenza/Helix XTra mixture and Prosper FX ranked highest in bioassays on striped flea beetles in dry soil.

Flea beetle mortality in the seed treatments at different temperatures and moisture conditions were correlated with feeding damage and fresh/dry weight of the seedlings

(Table 8). In bioassays on *P. cruciferae*, flea beetle mortality was negatively correlated (-r = 0.56-0.82; P ≤ 0.001) with feeding damage after 24, 48 and 72 h in wet and dry soil at 10, 20 and 30ºC. Mortality was positively correlated (r = 0.42-0.62; P ≤ 0.01-0.001) fresh weight in wet soil at 20ºC and 30ºC and dry soil at 10, 20 and 30ºC. In bioassays on *P. striolata*, flea beetle mortality was negatively correlated (-r = 0.50-0.77; P ≤ 0.01-0.001) with feeding damage after 24, 48 and 72 h in wet soil at 20ºC and 30ºC and dry soil at 10, 20 and 30ºC. Mortality was more strongly correlated with fresh weight in dry soil a 20ºC and 30ºC (r = 0.59-0.61; P ≤ 0.001) than in wet soil at 20ºC and 30ºC (r = 0.23-0.29; P ≥ 0.05).

Meteorological conditions in 2013

Air temperatures at Saskatoon ranged from -4.8°C to 28.9°C in May and from 2.0°C to 26.8°C in June (Table 9, Fig. 21). Average daily air temperatures were 1.5°C above normal in May and 0.5°C below normal in June. Daily min/max air temperatures for the first 28 days after seeding on May 17 ranged from 2.0°C to 24.7°C. Soil temperatures (5.0 cm depth) were relatively stable between May 17 and June 25 (Fig. 22). Average daily soil temperatures during this period ranged between 14°C and 21°C. Rainfall was below normal in May (15.2 mm) and near twice the norm in June (115.9 mm) (Table 9). The highest precipitation occurred June 8 (17.2 mm), June 13-15 (50.7 mm), June 19-22 (38.8 mm) and July 6 (15.2 mm) (Fig. 23). Soil moisture varied greatly depending on rainfall (Fig. 23). Moisture averaged 28% in late May, 20% in early June and 38-40% in mid to late June. Moisture levels declined from 25-30% in early July to 13% in late July. Levels also declined from 28% in early August to 10% in late August.

Roundup Ready (RR) hybrid canola

Populations of hop, striped and crucifer flea beetles in untreated RR canola varied markedly throughout the growing season (Fig. 24). Between May 30 and July 12, weekly catches of hop flea beetles ranged from 0.8 to 2.8 beetles per sticky card. Weekly catches of striped flea beetles ranged from 1 to 22 beetles per card. The highest numbers of striped flea beetles were collected June 14. Weekly catches of crucifer flea beetles ranged from 0 to 62 beetles per card. The highest numbers of crucifer flea beetles were collected June 21. The summer generation of striped flea beetles started to emerge July 26, about 2 weeks before emergence of the summer generation of crucifer flea beetles.

Numbers of crucifer, striped and hop flea beetles varied during emergence of RR canola (Fig. 25). Striped flea beetles were the most abundant species (73% total flea beetle population) when feeding damage was assessed 14 DAS. Crucifer flea beetles were the most common species (60% total) when damage was assessed 21DAS.

Seed treatments had a significant effect (F = 2.8-8.8; df = 12, 36; P = 0.01-0.001) on flea beetle damage to the cotyledons of RR canola 14, 19 and 21 days after seeding (Fig. 26). Flea beetle damage on each sampling date was highest in the untreated check and Tribune treatment. Damage after 14, 19 and 21 days averaged 11-12%, 18-19% and 18-19%, respectively. Gaucho CS FL, Helix, Prosper Evergol, Helix XTra, Fortenza/Helix XTra mixture, EX 2 and Lumiderm/Helix XTra mixture reduced damage to 2-5% after 14 days, 9-13% after 19 days and 13-15% after 21 days. Plants grown from seeds treated with the Fortenza/Helix XTra mixture or Lumiderm/Helix XTra mixture had the least damage after 21 days.

Seed treatments had a significant effect (F = 3.1-4.0; df = 12, 36; P = 0.01-0.001) on emergence and establishment of RR canola (Fig. 27). Seedlings grown from untreated seeds or Tribune-treated seeds had the poorest emergence after 14 and 21days (66-69%) and poorest stand establishment after 35 days (72-74%). With the exception of Lumiderm, all seed treatments improved emergence after 14 days (74-83%) and 21 days (75-83%). Seedlings grown from seeds treated with a neonicotinoid seed treatment (Gaucho CS FL, Helix, Prosper Evergol or Helix XTra), diamide seed treatment (Fortenza), experimental treatment (EX 2) or diamide/neonicotinoid mixture (Lumiderm/Prosper, Lumiderm/Helix XTra or Fortenza/Helix XTra) had the best stand establishment (81-86%) after 35 days. Compared to Tribune, the treatments improved stand establishment by 7-12% after 21 days.

Seed treatments had no effect (F = 1.3; df = 12, 36; P ≥ 0.05) on the fresh weight of RR canola after 14 days and no effect (F = 1.1-1.6; df = 12, 36; P ≥ 0.05) on the dry weight of RR canola after 14, 21 and 33 days (Figs. 28 and 29). Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, EX 2, Fortenza/Helix XTra mixture, Lumiderm/Prosper mixture or Lumiderm/Helix XTra mixture had the highest fresh weight after 21 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture or Fortenza/ Helix XTra mixture had the highest fresh weight after 33 days. Compared to Tribune, the treatments improved fresh weight by 1.1-1.3 times.

Seed treatments had a significant effect (F = 2.6-5.5; df = 12, 36; P = 0.05-0.001) on the shoot biomass of RR canola after 21 and 33 days (Fig 30). Plants grown from seeds treated with Prosper Evergol, Helix XTra, EX 2, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture or Fortenza/Helix XTra mixture had the highest shoot biomass after 21 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture or Fortenza/Helix XTra mixture had the highest shoot biomass after 33 days. Compared to Tribune, the treatments improved shoot biomass by 1.2-1.5 times.

Seed treatments had a significant effect (F = 2.3; df = 12, 36; P ≤ 0.05) on the seed yield of RR canola (Fig 31). Seed yields were lowest with untreated seed (299.4 g/m^2) and Tribune-treated seed (313.2 g/m^2). Plants grown from seeds treated with Gaucho CS FL, Helix XTra, Fortenza, Lumiderm, Lumiderm/Prosper mixture, Lumiderm/Helix, XTra mixture or Fortenza/Helix XTra mixture had the highest yields (328-338 g/m^2). Compared to Tribune, the treatments improved seed yield by 4-8%.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 10). Based on these criteria, the Lumiderm/Helix XTra mixture, Fortenza/Helix XTra mixture, Helix XTra and Lumiderm/Prosper mixture had the highest rankings in RR canola.

Clearfield (CL) hybrid canola

Low numbers of hop flea beetles were collected on yellow sticky cards in untreated Clearfield canola (Fig. 32). Between May 30 and July 12, weekly catches of hop flea beetles averaged less than one beetle per card. During this period, numbers of striped flea beetles averaged 1 to 20 beetles per card. The highest numbers were collected on June 14. Weekly catches of crucifer flea beetles were higher, reaching nearly 45 beetles per card on June 21. The summer generation of striped flea beetles started to emerge

July 26, about 2 weeks before emergence of the summer generation of crucifer flea beetles.

Numbers of crucifer, striped and hop flea beetles varied during emergence of CL canola (Fig. 33). Striped flea beetles were the most abundant species when feeding damage was assessed after 14 days (66%) and 20 days (54%). On these sampling dates, crucifer flea beetles comprised 32% and 44% of the total flea beetle population.

Seed treatments had a significant effect (F = 2.3-4.6; df = 12, 36; P = 0.05-0.001) on flea beetle damage to the cotyledons of Clearfield canola after 14 and 20 days (Fig. 34). Damage to seedlings grown from untreated seed and Tribune-treated seed averaged 12-14% after 14 days and 15-19% after 18 and 21 days. With the exception of Gaucho CS FL and Lumiderm, all treatments reduced damage relative to the check treatments after 14 days (3-6% damage). Seedlings grown from seeds treated with Gaucho CS FL, Lumiderm/Prosper mixture or Lumiderm/Helix XTra mixture had the least damage (10-11% damage) after 21 days. Compared to Tribune, the treatments reduced flea beetle damage by 3-4%.

Seed treatments had a significant effect (F = 4.9-5.4; df = 12, 36; P ≤ 0.001) on emergence and establishment of Clearfield canola (Fig. 35). Emergence after 14, 20 and 34 days was lowest in plants grown from untreated seeds (61, 64 and 72%, respectively) and Tribune-treated seeds (61, 64 and 73, respectively). Compared to the checks, all remaining treatments improved emergence after 14 days (73-79% emergence) and 21 days (74-81% emergence). Plants grown from seeds treated with Gaucho CS FL, Helix, Prosper Evergol or Helix XTra, Lumiderm, Fortenza, EX 2, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture or Fortenza/Helix XTra mixture had the highest stand establishment (82-89% establishment) after 28 days. Compared to Tribune, the treatments improved stand establishment by 10-16%.

Seed treatments had no effect on the fresh weight (F = 0.8-1.7; df = 12, 36; P ≥ 0.05) and dry matter content (F = 0.6-1.7; df = 12, 36; P ≥ 0.05) of Clearfield canola after 14, 20 and 32 days (Figs. 36 and 37).

Seed treatments had a significant effect (F = 2.4-2.6; df = 12, 36; P ≤ 0.05) on the shoot biomass of Clearfield canola after 14, 20 days and 32 days (Fig 38). Plants grown from untreated seeds and Tribune-treated seeds had the lowest biomass on each sampling date. Plants grown from seeds treated with Gaucho CS FL, Helix, Helix XTra, Lumiderm/Helix XTra mixture or Fortenza/Helix XTra mixture had the highest shoot biomass after 14 days. Plants grown from seeds treated with Gaucho CS FL, Helix XTra, EX 2 or Fortenza/Helix XTra mixture had the highest biomass after 20 days. Plants grown from seeds treated with Helix, Prosper Evergol, Helix XTra or Fortenza/Helix XTra mixture had the highest shoot biomass after 32 days. Compared to Tribune, the treatments improved shoot biomass by 1.4-1.7 times.

Seed treatments had no effect (F = 1.6; df = 12, 36; P ≥ 0.05) on the seed yield of Clearfield canola (Fig. 39). Yields averaged 353 g/m^2 over all treatments.

Seed treatments were ranked in terms of damage, stand establishment, biomass and seed yield (Table 11). The Lumiderm/Helix XTra mixture and Lumiderm/Prosper mixture had the highest ranking in Clearfield canola.

Canola mustard

Weekly catches of hop, striped and crucifer flea beetles in untreated canola mustard varied greatly throughout the growing season (Fig. 40). Hop flea beetles were the least common species. Weekly catches averaged 0-5 beetles per card between May 30 and August 25. Striped flea beetles were more common. Weekly catches ranged from 2-23 beetles per card between May 30 and July 12. The highest numbers of striped flea beetles were collected June 14. Crucifer flea beetles were the most abundant species. Weekly catches ranged from 1-233 beetles per card between May 30 and July 12. The highest numbers of crucifer flea beetles were collected on June 21. The summer generation of striped flea beetles started to emerge between July 26 and August 3, about 2 weeks before emergence of the summer generation of crucifer flea beetles.

Numbers of crucifer, striped and hop flea beetles varied during emergence of CL canola (Fig. 41). Crucifer flea beetles were the most abundant species when feeding damage was assessed after 14 days (53%) and 20 days (58%). On each sampling date, striped flea beetles comprised 37% of the total flea beetle population.

Seed treatments had a significant effect ($F = 8.6\text{-}15.8$; $df = 12, 36$; $P \leq 0.001$) on flea beetle damage to the cotyledons of canola mustard 14, 18 and 21 days after seeding (Fig. 42). Flea beetle damage was highest in the untreated check, averaging 53% after 14 days, 53% after 18 days and 44% after 21 days. Damage was also very high in the Tribune treatment, averaging 32% after 14 days, 40% after 18 days and 43% after 21 days. All remaining treatments except EX 1 and Fortenza reduced damage to 2-8% after 14 days, 7-15% after 18 days and 12-19% after 21 days. Compared to Tribune, the treatments reduced feeding damage by 23-30%.

Seed treatments had a significant effect ($F = 4.5\text{-}8.9$; $df = 12, 36$; $P \leq 0.001$) on emergence and establishment of canola mustard (Fig. 43). Seedling counts after 14, 21 and 28 days were lowest with untreated seeds and Tribune-treated seeds. Emergence and establishment after 14, 21 and 28 days averaged 33, 30 and 29%, respectively, with untreated seeds and 34, 33 and 34%, respectively, with Tribune-treated seeds. Plants grown from seeds treated with Gaucho CS FL, Helix, Prosper Evergol, Helix XTra, Fortenza, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture or Fortenza/Helix XTra mixture had the best emergence after 14 days (50-54% emergence) and 21 days (47-54% emergence). All treatments except EX 1, EX 2 and Lumiderm had the highest plant counts and best establishment (50-54% establishment) after 28 days. Compared to Tribune, the treatments improved stand establishment by 15-20%.

Seed treatments had a significant effect on the fresh weight ($F = 2.7\text{-}4.2$; $df = 12, 36$; $P \leq 0.05$) and dry matter content ($F = 2.5\text{-}4.0$; $df = 12, 36$; $P \leq 0.05$) of canola mustard after 14, 21 and 28 days (Figs. 44 and 45). On most sampling dates, plants grown from untreated seeds or Tribune-treated seeds had the lowest fresh weight and lowest dry matter content. Plants from all remaining treatments except Lumiderm had the highest fresh weight and dry matter after 21 days. Plants from all treatments except Gaucho CS FL, Helix XTra and EX 1 had the highest fresh weight and highest dry matter content after 28 days. Compared to Tribune, the treatments improved fresh weight by 1.5-2.0 times and dry matter by 1.3-1.9 times.

Seed treatments had a significant effect ($F = 3.7\text{-}5.3$; $df = 12, 36$; $P \leq 0.01$) on the shoot biomass of canola mustard after 14, 21 and 28 days (Fig. 46). Plants grown from untreated seeds and Tribune-treated seeds had the lowest shoot biomass on each sampling date. Plants grown from seeds treated with a neonicotinoid seed treatment (Helix, Prosper Evergol or Helix XTra), diamide seed treatment (Fortenza or Lumiderm), experimental seed treatment (EX2) or mixture (Lumiderm/Prosper, Lumiderm/Helix XTra or Fortenza/Helix XTra) had the highest shoot biomass after 14, 21 and 28 days. Compared to Tribune, the treatments improved shoot biomass by 2.2-3.1 times after 28 days.

Seed treatments had a significant effect ($F = 2.5$; $df = 12, 36$; $P \leq 0.05$) on the seed yield of canola mustard (Fig. 47). Seed yields were lowest with untreated seeds (264 g/m^2) and Tribune-treated seeds (279.5 g/m^2). Plants grown from seeds treated with a neonicotinoid seed treatment (Gaucho CS FL or Helix), diamide seed treatment (Fortenza), experimental seed treatment (EX 2) or mixture (Lumiderm/Prosper, Lumiderm/Helix XTra or Fortenza/Helix XTra) had the highest seed yield (306-329 g/m^2). Compared to Tribune, the treatments improved yield by 10-18%.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 12). The Fortenza/Helix XTra mixture, Lumiderm/Helix XTra mixture, Lumiderm/Prosper mixture, Helix and Prosper Evergol had the highest rankings in canola mustard.

Meteorological conditions in 2014

Saskatoon experienced a cool wet spring in 2014. Air temperatures ranged from -4.8°C to 30.9°C in May and from 1.0°C to 25.4°C in June (Table 13, Fig. 48). Daily air temperatures were 1.1°C below normal in May and 1.7°C below normal in June. Daily min/max air temperatures for the first 28 days after seeding ranged from -4.0°C on May 13 to 30.9°C on May 23. Daily min/max soil temperatures during this period ranged between 9°C and 27°C. Average daily soil temperatures at 5-cm depth ranged between 13°C and 21°C (Fig. 49) Rainfall was 20 mm above normal in May and 30 mm above normal in June. The highest precipitation occurred May 19 (16.8 mm), May 26 (22.3 mm), May 29 (19.7 mm), June 14-15 (17.9 mm) and June 18-22 (54.3 mm) (Fig. 50). Moisture conditions were excellent from seeding until early July. Moisture averaged 28-44% during May and 27-48% during June and early July. Low temperatures and above-average precipitation reduced the activity of flea beetles and leafhoppers in the plots. Activity was also reduced by high winds in early June (June 4-10) when wind gusts often exceeded 50 km/h.

Roundup Ready (RR) hybrid canola

Weekly flea beetle counts on yellow sticky cards in hybrid canola varied greatly throughout the growing season (Fig. 51). Hop flea beetles were the least common species. On most sampling dates, weekly catches of hop flea beetles averaged less than 7 beetles per card from late May until early July. Hop flea beetles comprised less than 5% of the total flea beetle population during this period. Striped flea beetles were more common. The highest numbers of striped flea beetles were collected on May 25 (>145 beetles/card) and June 29 (>65 beetles/card). The fall generation of striped flea beetles started to emerge between July 20 and July 27. The fall generation of crucifer flea beetles emerged 2-3 weeks later between August 3 and August 10.

Numbers of crucifer, striped and hop flea beetles varied during emergence and establishment of Clearfield canola (Fig. 52). Striped flea beetles were the most common species when feeding damage was assessed after 14 days (81%) and 21 days (72%). On each sampling date, crucifer flea beetles comprised 15% and 24% of the total flea beetle population.

Seed treatments had a significant effect (F = 4.1-18.3; df = 9, 27; P = 0.01-0.001) on flea beetle damage to the cotyledons of RR canola (Fig. 53). Flea beetle damage was highest in the untreated check and Tribune treatment. Damage 15, 18 and 21 DAS averaged 30-33%, 39-44% and 45-47%, respectively. Plants grown from seeds treated with Gaucho CS FL, Prosper Evergol, Helix XTra, EX 2 or Fortenza/Helix XTra mixture had the lowest damage (12-17% damage) after 15 days. Plants grown from seeds treated with Gaucho CS FL, Fortenza, EX 2 or Fortenza/Helix XTra mixture had the least damage (22-29% damage) after 18 days. Compared to the checks, all treatments except EX 1 reduced damage (33-36% damage) after 21 days. Although the treatments reduced flea beetle feeding damage by 9-13% compared to Tribune, damage exceeded the economic threshold in all treatments after 21 days.

Seed treatments had a significant effect (F = 15.8-24.7; df = 9, 27; P ≤ 0.001) on emergence and establishment of RR canola (Fig. 54). Seedlings grown from untreated seeds or Tribune-treated seeds had the poorest emergence after 15 days (47-48%) and 21 days (44-46%) and poorest stand establishment after 28 days (47-48%). Plants grown from seeds treated with Gaucho CS FL, Prosper Evergol, Helix XTra, EX 2 or Fortenza/Helix XTra mixture had the highest emergence after 15 days (84-91% emergence) and 21 days (78-87% emergence) and best stand establishment after 28 days (83-89% establishment). Compared to Tribune, the treatments improved stand establishment by 36-42%.

Seed treatments had a significant effect on the fresh weight (F = 6.4-16.3; df = 9, 27; P ≤ 0.001) and dry matter content (F = 6.3-13.1; df = 9, 27; P ≤ 0.001) of RR canola (Figs. 55 and 56). Plants grown from untreated seeds or Tribune-treated seeds had the lowest fresh weight and lowest dry matter after 15, 21 and 28 days. Plants grown from seeds treated with Prosper Evergol, Fortenza, EX 2 or the Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 15 days and 21 days. Compared to Tribune-treated seeds, the treatments improved fresh weight and dry matter by 1.5-1.8 times after 15 days and fresh weight and dry matter by 1.7-2.0 times after 21 days. Plants grown from seeds treated with Helix XTra, Fortenza or Fortenza/Helix XTra mixture had the highest fresh weight after 28 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, EX 2 or Fortenza/Helix XTra mixture had the highest dry matter after 28 days. Compared to Tribune, the treatments improved fresh weight by 2.5-3.0 times and dry matter by 2.2-2.7 times.

Seed treatments had a significant effect (F = 12.4-25.5; df = 9, 27; P ≤ 0.001) on the shoot biomass of RR canola after 15, 21 and 28 days (Fig. 57). Plants grown from untreated seeds and Tribune-treated seeds had the lowest shoot biomass on each sampling date. Plants grown from seeds treated with Prosper Evergol or Fortenza/Helix XTra mixture had the highest shoot biomass after 15 and 21 days. Compared to Tribune, the treatments improved biomass by 3.3 times after 15 days and by 3.4-3.6 times after 21 days. Plants grown from seeds treated with the Fortenza/Helix XTra mixture had the highest shoot biomass after 28 days. Compared to Tribune, the mixture improved biomass after 28 days by 5.5 times. Prosper Evergol, Helix XTra, Fortenza and the Fortenza/Helix XTra mixture improved biomass after 28 days by 4.1-5.5 times.

Seed treatments had a significant effect (F = 8.0; df = 9, 27; P ≤ 0.001) on the seed yield of RR canola (Fig. 58). Seed yields were lowest with untreated seeds (335.6 g/m^2)

and Tribune-treated seeds (304.2 g/m^2). Plants treated with Prosper Evergol (389.6 g/m^2) or Fortenza/ Helix XTra mixture (392.3 g/m^2) had the highest seed yield. Compared to Tribune, the treatments improved yield by 28-29%. Seed yields with Helix XTra (375.4 g/m^2), Fortenza (374.9 g/m^2) or EX 2 (383.9 g/m^2) were 23-26% higher than with Tribune.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 14). Prosper Evergol, Fortenza/Helix XTra mixture, EX 2 and Helix XTra had the highest rankings in Roundup Ready canola.

Canola mustard

Weekly catches of hop, striped and crucifer flea beetles on sticky cards in canola mustard varied greatly between May 25 and August 10 (Fig. 59). Populations of hop flea beetles were very low, averaging less than 9 beetles per card on most sampling dates. In contrast, weekly catches of striped flea beetles ranged from 25 to 90 beetles per card between May 25 and June 22. Subsequent catches exceeded 200 beetles per card between June 29 and July 6. Weekly catches of crucifer flea beetles exceeded 200 beetles per card between June 15 and June 29. The fall generation of striped flea beetles started to emerge July 20, about 14 days before emergence of the fall generation of crucifer flea beetles.

Numbers of crucifer, striped and hop flea beetles varied during emergence and establishment of canola mustard (Fig. 60). Striped flea beetles were the most common species when feeding damage was assessed after 14 days (72%) and 21 days (49%). On each sampling date, crucifer flea beetles comprised 22% and 48% of the total flea beetle population.

Seed treatments had a significant effect ($F = 2.8\text{-}4.2$; $df = 9, 27$; $P = 0.05\text{-}0.01$) on flea beetle damage to the cotyledons of canola mustard (Fig. 61). Flea beetle damage was highest in the Tribune treatment, averaging 22% after 15 days, 38% after 18 days and 42% after 21 days. Damage was also very high in the untreated check, averaging 15% after 15 days, 37% after 18 days and 42% after 22 days. Plants grown from seeds treated with Gaucho CS FL, Helix XTra, Fortenza, EX 2 or Fortenza/Helix XTra mixture had the lowest damage (9-13%) after 15 days. Plants grown from seeds treated with Helix XTra, Fortenza or Fortenza/Helix XTra mixture had the least damage (25-31% damage) after 22 days. The treatments reduced damage by 11-16% compared to Tribune.

Most seed treatments had a significant effect ($F = 12.1\text{-}16.6$; $df = 9, 27$; $P \leq 0.001$) on emergence and establishment of canola mustard (Fig. 62). Seedling counts after 15, 21 and 28 days were lowest with untreated seeds, Tribune-treated seeds and seeds treated with EX 2. Emergence in the treatments averaged 30-36% after 15 days and 30-33% after 21 days. Stand establishment with the treatments averaged 31-33% after 28 days. Plants grown from seeds treated with Gaucho CS FL, Prosper Evergol, Fortenza or Fortenza/Helix XTra mixture had the highest seedling counts (50-55% emergence) after 15 days and after 28 days (48-55% establishment) Compared to Tribune, the treatments improved stand establishment by 16-23% after 28 days.

Seed treatments had a significant effect on the fresh weight and dry matter content of canola mustard after 15 days ($F = 2.3\text{-}2.4$; $df = 9, 27$; $P \leq 0.05$) but not after 22 and 28 days ($F = 1.7\text{-}2.2$; $df = 9, 27$; $P \geq 0.05$) (Figs. 63 and 64). Plants grown from untreated seeds or Tribune-treated seeds had the lowest fresh weight and lowest dry matter on most sampling dates. Plants grown from seeds treated with Prosper Evergol, Fortenza or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 15 days. Plants grown from seeds treated with Helix XTra, Fortenza or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 28 days. Compared to Tribune, the treatments improved fresh weight and dry matter by 1.6-1.8 times after 28 days.

Seed treatments had a significant effect ($F = 6.3\text{-}6.9$; $df = 9, 27$; $P \leq 0.001$) on the shoot biomass of canola mustard after 15, 22 and 28 days (Fig. 65). Plants grown from untreated seeds and Tribune-treated seeds had the lowest shoot biomass on each sampling date. Plants grown from seeds treated with Prosper Evergol, Fortenza or Fortenza/Helix XTra mixture had the highest shoot biomass after 15 days. Plants grown from seeds treated with Helix XTra, Fortenza or Fortenza/Helix XTra mixture had the highest biomass after 28 days. Compared to Tribune, the treatments improved shoot biomass by 2.6-2.7 times after 28 days.

Most seed treatments had a no effect ($F = 2.2$; $df = 9, 27$; $P \geq 0.05$) on the seed yield of canola mustard (Fig. 66). Seed yields ranged from 292.4 g/m^2 with untreated seed to 334.1 g/m^2 with Fortenza. Plants grown from seeds treated with Fortenza or Fortenza/Helix XTra mixture had the highest seed yield. The treatments improved seed yield by 7-11% compared to Tribune.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 15). The Fortenza/Helix XTra mixture, Fortenza, Helix XTra and Gaucho CS FL had the highest rankings in canola mustard.

Meteorological conditions in 2015

Air temperatures at Saskatoon ranged from -5.7°C to 28.9°C in May and from 2.3°C to 33.4°C in June (Table 16, Fig. 67). Average daily air temperatures were 1.1°C below normal in May and 1.4°C above normal in June. Daily min/max air temperatures for the first 28 days after seeding on May 13 ranged from -5.7°C to 33.3°C. Rainfall was 40 mm below normal in May (0.4 mm) and 50 mm below normal in June (13.6 mm). Soil temperatures at 5-cm depth increased from 12ºC in early May to 20ºC in early June (Fig. 68). The highest precipitation occurred June 12 (5.8 mm), June 14 (1.2 mm) and June 20 (6.6 mm) (Fig. 69). Soil moisture ranged from 16-30% in May and from 11-21% in June (Fig. 69). Moisture levels were highest (24-34%) in late July and throughout August.

Roundup Ready (RR) hybrid canola

Weekly counts on sticky cards indicated that flea beetles were present in untreated buffer plots of RR canola throughout most of the growing season (Fig. 70). Spring populations of hop, crucifer and striped flea beetles were present from mid-May until early July. Fall populations of the three species were present from July 11 through early September. Hop flea beetles were the least common species. Weekly counts reached 3-7 beetles/card on May 16-23 then declined to less than 1 beetle/card for the rest of the growing season. Hop flea beetles comprised less than 1% of the total flea beetle population on all sampling dates. Crucifer flea beetles were the second most common species. Numbers of crucifer flea beetles peaked on May 23 (155 beetles/card). The fall generation started to emerge July 18-25. Numbers peaked on August 15 (205 beetles/card) then declined to no beetles/card on September 5. Striped flea beetles were the most common species in May. Counts reached 1350 beetles/card on May 23. These were the highest flea beetle counts ever recorded at AAFC-Saskatoon. The fall population of striped flea beetles started to emerge July 11-18 and reached their highest numbers between July 25 and August 1 (165-205 beetles/card). No striped flea beetles were collected after August 29.

Numbers of crucifer, striped and hop flea beetles varied during emergence and establishment of canola mustard (Fig. 71). Striped flea beetles were the most common species when feeding damage was assessed after 14 days (91%) and 21 days (91%). Crucifer flea beetles comprised 9% of the total flea beetle population on each sampling date.

Seed treatments had a significant effect on flea beetle damage to the cotyledons of RR canola after 14 days ($F = 9.1$; df = 10, 30; $P \leq 0.001$) and 19 days ($F = 2.2$; df = 10, 30; $P \leq 0.05$) but not after 21 days ($F = 2.0$; df = 10, 30; $P \geq 0.05$) (Fig. 72). Flea beetle damage was very high in the untreated check and Tribune treatment. Damage 14, 19 and 21 DAS averaged 45-53%, 59-62% and 63-64%, respectively. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the lowest flea beetle damage (13-19% damage) after 14 days. Plants grown from seeds treated with Prosper Evergol, Fortenza, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the lowest damage after 19 days (34-48% damage) and 21 days (42-56% damage). Compared to Tribune, the treatments reduced flea beetle damage by 15-28% after 19 days and by 7-21% after 21 days. However, damage exceeded the economic threshold in all treatments after 19 days.

Seed treatments had a significant effect ($F = 4.3$-5.8; df = 10. 30; $P = 0.01$-0.001) on emergence of RR canola after 13 and 20 days (Fig. 73). Seedlings grown from untreated seeds or Tribune-treated seeds had the poorest emergence after 14 days (45-47%) and poorest establishment after 20 days (22%). Frost reduced emergence by an estimated 10% after 13-20 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest seedling counts (64-73% emergence) after 13 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza or Fortenza/Helix XTra mixture had the highest counts (48-62% establishment) after 20 days. The treatments improved stand establishment by 21-35% compared to Tribune.

Seed treatments had a significant effect on the fresh weight ($F = 7.3$-13.2; df = 10, 30; $P \leq 0.001$) and dry matter content ($F = 2.9$-12.3; df = 10, 30; $P = 0.01$-0.001) of RR canola (Figs. 74 and 75). Plants grown from untreated seeds or Tribune-treated seeds had the lowest fresh weight and lowest dry matter after 14, 21 and 28 days. Plants grown from seeds treated with EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 14 days. Plants grown from seeds treated with Prosper Evergol, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 28 days. Compared to Tribune, the treatments improved fresh weight and dry matter by 2.3-3.2 times after 28 days.

Seed treatments had a significant effect ($F = 5.7$-10.9; df = 10, 30; $P \leq 0.001$) on the shoot biomass of RR canola after 14, 21 and 28 days (Fig. 76). Plants grown from untreated seeds and Tribune-treated seeds had the lowest shoot biomass on each sampling date. Plants grown from seeds treated with EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest shoot biomass after 14 days. Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest biomass after 28 days. Compared to Tribune, the treatments improved biomass by 4.1-6.6 times after 28 days.

Seed treatments had a significant effect ($F = 5.0$; $df = 10, 30$; $P \leq 0.001$) on the seed yield of RR canola (Fig. 77). Seed yields were lowest with untreated seed (192 g/m^2) and Tribune-treated seed (198 g/m2). Plants grown from seeds treated with Prosper Evergol, Helix XTra, Fortenza, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest seed yields (253-269 g/m^2). Compared to Tribune, the treatments improved yield by 27-36%.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 17). Prosper Evergol, Fortenza/Helix XTra mixture, Fortenza and Fortenza/Helix mixture had the highest rankings in Roundup Ready canola.

Clearfield (CL) hybrid canola

Weekly flea beetle counts in buffer plots of CL canola varied greatly throughout the growing season (Fig. 78). Spring populations of hop, crucifer and striped flea beetles were present from May 23 to July 4. Fall populations of the three species were present from July 11 until September 12. Hop flea beetles were the least common species. Weekly counts reached 4 beetles per card on May 23 then declined to less than 1 beetle/trap for the remainder of the growing season. Hop flea beetles comprised less than 1% of the total flea beetle population on all sampling dates. Crucifer flea beetles were the second most common species. Numbers of crucifer flea beetles peaked on June 20 (80 beetles/card). The fall generation started to emerge July 25. Numbers peaked on August 22 (570 beetles/card) then declined to no beetles/trap on September 12. Striped flea beetles were the most common species in May. Counts reached 60-65 beetles/card on May 30 and June 6. The fall population of striped flea beetles started to emerge July 11 and reached their highest numbers July 25 (270 beetles/card) and August 8 (290 beetles/card). No striped flea beetles were collected after August 29.

Numbers of crucifer, striped and hop flea beetles varied during emergence and establishment of canola mustard (Fig. 79). Striped flea beetles were the most common species when feeding damage was assessed after 14 days (91%) and 21 days (65%). Crucifer flea beetles comprised 9% of the total flea beetle population after 14 days and 35% of the total population after 21 days.

Seed treatments had a significant effect on flea beetle damage to the cotyledons of CL canola after 14 days ($F = 12.1$; $df = 10, 30$; $P \leq 0.001$), 17 days ($F = 4.4$; $df = 10, 30$; $P \leq 0.001$) but not after 21 days ($F = 1.2$; $df = 10, 30$; $P \geq 0.05$) (Fig. 80). Flea beetle damage was highest in the untreated check and Tribune treatment, averaging 26-29% after 14 days, 30-35% after 17 days and 41% after 21 days. Plants grown from seeds treated with Gaucho CS FL, Prosper Evergol, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the lowest flea beetle damage after 14 days (9-13% damage) and 17 days (20-26% damage). Compared to Tribune, the treatments reduced flea beetle damage by 16-21% after 14 days and by 9-15% after 17 days. Damage was not significantly different among treatments after 21 days when damage exceeded the economic threshold in all treatments.

Seed treatments had a significant effect on emergence and establishment of CL canola after 14, 21 and 28 days ($F = 2.9$-3.8; df = 10, 30; $P = 0.05$-0.01) (Fig. 81). Seedlings grown from untreated seeds or Tribune-treated seeds had the poorest emergence after 14 days (50-54%) and 21 days (46-48%) and poorest stand establishment after 28 days (44-48%). Plants grown from seeds treated with Gaucho CS FL, Prosper Evergol, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest seedling counts after 14 days (63-74% emergence) and 28 days (58-71% establishment). Compared to Tribune, the treatments improved stand establishment by 13-26% after 28 days.

Seed treatments had a significant effect on the fresh weight and dry matter content of CL canola after 14 days ($F = 2.2$-3.1; df = 10, 30; $P = 0.05$-0.01) but not after 21 and 28 days ($F = 1.8$-2.1; df = 10, 30; $P \geq 0.05$) (Figs. 82 and 83). Plants grown from seeds treated with Helix, Prosper Evergol, Helix XTra, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 14 days. Plants grown from seeds treated with Prosper Evergol, EX 2 or Fortenza/Helix XTra mixture had the highest fresh weight and highest dry matter after 28 days. Compared to Tribune, the treatments improved fresh weight and dry matter by 1.5-1.6 times after 28 days.

Seed treatments had a significant effect on the shoot biomass of CL canola after 14 days ($F = 4.5$; df = 10, 30; $P \leq 0.001$), 21 days ($F = 3.7$; df = 10, 30; $P \leq 0.01$) and 28 days ($F = 4.5$; df = 10, 30; $P \leq 0.001$) (Fig. 84). Plants grown from untreated seeds and Tribune-treated seeds had the lowest shoot biomass on each sampling date. Plants grown from seeds treated with Prosper Evergol, Fortenza, EX 2, Fortenza/Helix mixture or Fortenza/Helix XTra mixture had the highest shoot biomass after 14 days and 28 days. Compared to Tribune, the treatments improved shoot biomass by 1.9-2.4 times after 28 days.

Seed treatments had a significant effect ($F = 2.4$; df = 10, 30; $P \leq 0.05$) on the seed yield of CL canola (Fig. 85). Seed yields were lowest with untreated seed (249.6 g/m^2) and Tribune-treated seed (238.5 g/m^2). Plants grown from seeds treated with Gaucho CS FL, Fortenza, EX 2 or Fortenza/Helix XTra mixture had the highest seed yields (269-277 g/m^2). The treatments improved seed yield by 12-16% compared to Tribune.

Seed treatments were ranked on their ability to reduce flea beetle feeding damage and improve stand establishment, biomass and seed yield (Table 18). EX 2, the Fortenza/Helix XTra mixture, Fortenza/Helix mixture and Prosper Evergol had the highest rankings in Clearfield canola.

Statistical correlations

Pearson correlations between flea beetle damage in seed treatments after 14 days and subsequent agronomic performance was assessed in each canola type (Table 19). In each field test (7/7 tests), damage in seed treatments after 14 days was negatively correlated ($-r = 0.43$-0.86; $P = 0.01$-0.001) with stand establishment after 21 days. In most tests (6/7 tests), damage after 14 days was negatively correlated with plant fresh weights after 14, 21 and 28 days ($-r = 0.30$-0.78; $P = 0.05$-0.001); dry matter content after 14, 21 and 28 days ($-r = 0.37$-0.79; $P = 0.01$-0.001) and shoot biomass after 14, 21 and 28 days ($-r = 0.38$-0.74; $P = 0.01$-0.001). The correlations indicated that seed treatments that provide the best protection against flea beetle damage after 14 days also provide the best stand establishment after 21 days and greatest improvements in plant weight after 14-28 days.

The efficacy of seed treatments against crucifer flea beetles in lab bioassays (% mortality) was correlated with the performance of the treatments in three canola types in the field (Table 20). In most tests, flea beetle mortality in the lab was negatively correlated with flea beetle damage after 14 days (-r = 0.74-0.90; P = 0.05-0.001; 6/7 tests) and positively correlated with stand establishment after 21 days (r = 0.70-0.86; P = 0.05-0.001; 6/7 tests); plant fresh weight after 28 days (r = 0.73-0.85; P = 0.05-0.001; 5/7 tests) and shoot biomass after 28 days (r = 0.72-0.89; P = 0.05-0.001; 5/7 tests). Correlations were not significant on canola mustard in 2014 and CL canola in 2015. With these exceptions, the correlations indicated that seed treatments that provided the best control of crucifer flea beetles in the lab also provided the best stand establishment and greatest improvement in fresh weight and shoot biomass in the field.

The efficacy of seed treatments against crucifer flea beetles in lab bioassays (% damage) was correlated with the performance of the treatments in three canola types in the field (Table 21). In most tests, flea beetle damage in the lab was positively correlated with flea beetle damage after 14 days (r = 0.70-0.96; P = 0.05-0.001; 7/7 tests) and negatively correlated with seedling emergence after 14 days (-r = 0.74-0.98; P = 0.05-0.001; 6/7 tests); plant fresh weight after 28 days (-r = 0.61-0.89; P = 0.05-0.001; 5/7 tests) and shoot biomass after 28 days (-r = 0.0.70-0.93; P = 0.05-0.001; 5/7 tests). Correlations were not significant on canola mustard in 2014 and CL canola in 2015. In the remaining tests, seed treatments that provided the best protection against crucifer flea beetles in the lab also provided the best seedling emergence and greatest improvement in fresh weight and shoot biomass in the field.

The efficacy of seed treatments against striped flea beetles in lab bioassays (% mortality) was correlated with the performance of the treatments in three canola types in the field (Table 22). In some tests, flea beetle mortality in the lab was negatively correlated with flea beetle damage after 14 days (-r = 0.59-0.76; P = 0.05-0.01; 3/7 tests) and positively correlated with seedling emergence after 14 days (r = 0.63-0.68; P ≤ 0.05; 3/7 tests); plant fresh weight after 28 days (r = 0.66-0.90; P = 0.05-0.01; 4/7 tests) and shoot biomass after 28 days (r = 0.67-0.83; P = 0.05-0.01; 4/7 tests). Correlations were not significant in RR canola in 2015 and CL canola in 2013 and 2015. In the remaining tests, seed treatments that provided the best protection against striped flea beetles in the lab also provided the best seedling emergence and greatest improvement in fresh weight and shoot biomass in the field.

The efficacy of seed treatments against striped flea beetles in lab bioassays (% damage) was correlated with the performance of the treatments in three canola types in the field (Table 23). In some tests, flea beetle damage in the lab was positively correlated with flea beetle damage after 14 days (r = 0.61-0.72; P ≤ 0.05; 6/7 tests) and negatively correlated with seedling emergence after 14 days (-r = 0.66-0.77; P = 0.05-0.01; 4/7 tests); plant fresh weight after 28 days (-r = 0.59-83; P = 0.05-0.01; 2/7 tests) and shoot biomass after 28 days (-r = 0.61-0.81; P = 0.05-0.01; 3/7 tests). Correlations were not significant in RR canola in 2013 and 2015, CL canola in 2015 and canola mustard in 2013. In the remaining tests, seed treatments that provided the best protection against striped flea beetles in the lab also provided the best seedling emergence and greatest improvement in fresh weight and shoot biomass in the field.

DISCUSSION

In the current study, several criteria were used to evaluate the efficacy of seed treatments for control of flea beetles attacking canola. In lab bioassays, assessments at different temperatures and moisture regimes focused on identifying treatments that provide the 1) best flea beetle control after 72 h, 2) best protection against feeding damage after 24 and 72 h and 3) greatest improvement in seedling fresh weight and dry matter after 72 h. In field trials on three canola types, efficacy assessments focused on identifying seed treatments that provide the 1) best protection against flea beetle damage to the cotyledons after 14-21 days, 2) best emergence and stand establishment after 14-28 days and 3) greatest improvement in fresh weight, dry matter and shoot biomass after 14-28 days. Statistical correlations on data from seven field tests indicated that seed treatments that provide the best protection against flea beetle damage at the early cotyledon stage (13-14 days) also provide the best stand establishment (7/7 field tests) and greatest improvement in seedling fresh weight (6/7 tests), dry matter content (6/7tests) and shoot biomass (6/7 tests). Results in the three canola types indicate that flea beetle protection at the cotyledon stage has a major impact on the subsequent performance of hybrid canola. The efficacy of seed treatments in lab bioassays on crucifer flea beetles was strongly correlated with the performance of the treatments in the field. Seed treatments that gave the best control and protection against crucifer flea beetles in the lab also gave the best protection against flea beetle damage in the field (6/7 field tests), best stand establishment in the field (6/7 tests) and greatest improvement in fresh weight and shoot biomass in the field (5-6/7 tests). Seed treatments that gave the best protection against striped flea beetles in the lab bioassays also gave the best protection against flea beetle damage in the field (6/7 tests), best emergence and establishment (4/7 tests) and greatest improvement in fresh weight and shoot biomass (2-5/7tests). Results suggest that the efficacy of seed treatments in lab bioassays, particularly crucifer flea beetles, provided a reliable indication of their efficacy in the field.

Crucifer flea beetles

In lab bioassays, moisture conditions and temperature had a significant effect on the efficacy of neonicotinoid seed treatments against crucifer flea beetles. In the 2011 and 2012 bioassays, Gaucho CS FL, Helix, Prosper FX and Helix XTra provided significantly better control of crucifer flea beetles on plants grown in dry soil than on plants grown in wet soil. At each moisture regime, control was lowest at 10ºC, intermediate at 20ºC and highest at 30ºC. Over the range of conditions tested in 2011 and 2012, control of crucifer flea beetles was lowest in wet soil at 10ºC (8-28% mortality) and highest in dry soil at 30ºC (34-97% mortality). In each test year, Gaucho CS FL provided the poorest control of crucifer flea beetles in wet soil at 20ºC (18-26% mortality) and 30ºC (19-30% mortality) and dry soil at 20ºC (29-34% mortality) and 30ºC (34-58% mortality). Helix also provided relatively poor control of crucifer flea beetles in wet soil at 20ºC (25-42% mortality) and 30ºC (47% mortality). Over two years, Prosper FX and Helix XTra provided the best control of crucifer flea beetles in wet soil at 20ºC (48-53% mortality) and 30ºC (76-86% mortality) and dry soil at 20ºC (61-86% mortality) and 30ºC (85-97% mortality).

Several factors may have affected the efficacy of neonicotinoid seed treatments against crucifer flea beetles. In other crops, the uptake and translocation of neonicotinoid seed treatments has been shown to be influenced by the solubility of the insecticide in water, temperature and application rate (Jeschke et al. 2011; Bonmatin et al. 2015). Compared to other insecticides, clothianidin (340 mg/L), imidacloprid (610 mg/L) and thiamethoxam (4100 mg/L) have a moderate to high solubility in water. A moderate to high water solubility is advantageous in dry soil where moisture conditions limit the uptake and translocation of less soluble insecticides. High water solubility would explain the high beetle mortality with Helix and Helix XTra in dry soil. However, insecticides with high water solubility are prone to leaching and run-off. The high water solubility of thiamethoxam may explain the relatively poor control of crucifer flea beetles with Helix in wet soil where a low application rate (200 g per 100 kg seed) limited efficacy. Conversely, the moderate water solubility of clothianidin may explain the relatively high beetle control with Prosper FX in wet soil.

The uptake and translocation of neonicotinoid seed treatments in other crops is known to increase with higher temperatures. Increased uptake of insecticide at higher temperatures would explain the increase in beetle mortality with higher temperatures. However, higher temperatures also affected the feeding behaviour of crucifer flea beetles. In the 2011 and 2012 bioassays, feeding damage to the cotyledons of check plants was lowest at 10ºC (4-6% damage), moderate at 20ºC (10-15% damage) and highest at 30ºC (22-50% damage). Damage at 30ºC was higher in dry soil (35-51% damage) than in wet soil (22-29% damage). Results indicate that feeding damage by crucifer flea beetles doubled with each 10ºC increase in temperature. By consuming more foliage, beetles would ingest a toxic dose more rapidly at 20ºC and 30ºC than at 10ºC. A 5- to 10-fold increase in feeding activity between 10ºC and 30ºC would explain the high beetle mortality with neonicotinoids at 30ºC, particularly in dry soil.

Unlike beetle mortality, soil moisture and temperature had little effect on feeding damage to plants grown from seeds treated with a neonicotinoid seed treatment. Damage to plants grown with a neonicotinoid insecticide in dry soil was very low, averaging 3-4% at 10ºC, 3-5% at 20ºC and 4-7% at 30ºC. Corresponding damage to plants grown in wet soil was marginally higher, averaging 3-4% at 10ºC, 4-6% at 20ºC and 5-10% at 30ºC. Helix, Prosper FX and Helix XTra provided similar protection against crucifer flea beetles in dry and wet soil at 10ºC and 20ºC and dry soil at 30ºC. Prosper FX and Helix XTra provided the best protection (5-6% damage) in wet soil at 30ºC.

By reducing feeding damage, neonicotinoid seed treatments improved the fresh weight and dry matter of canola seedlings. Compared to Tribune, Helix, Prosper FX and Helix XTra improved seedling weight in the 2011 bioassay by 1.2-1.3 times in dry soil at 20ºC, by 1.5-1.6 times in wet soil at 30ºC and by 1.9-2.2 times in dry soil at 30ºC. In the 2012 bioassays, Helix, Prosper FX and Helix XTra improved seedling weight in by 1.2-1.4 times in wet soil at 30ºC and by 2.2-2.3 times in dry soil at 30ºC.

In terms of newly registered seed treatments, control, protection and improvements in seedling weight with Fortenza and Lumiderm in the 2011 bioassays were comparable to that obtained with Helix and Gaucho CS FL at most temperatures and moisture conditions. Control, protection and improvement in seedling weight with the

Lumiderm/Prosper mixture were comparable to that with Prosper FX or Helix XTra at most conditions. In the 2012 bioassays, the efficacy of EX 2 and the Fortenza/Helix XTra mixture was comparable to that of Prosper FX and Helix XTra at most conditions.

Striped flea beetles

In the 2011 and 2012 bioassays, neonicotinoid seed treatments provided poor control of striped flea beetles. In bioassays in wet soil, mortality with neonicotinoid seed treatments was very low at 10ºC (0-9% mortality), 20ºC (3-18% mortality) and 30ºC (1-18% mortality). In bioassays in dry soil, mortality in the treatments was lower at 10ºC (3-14% mortality) and 20ºC (13-19% mortality) than at 30ºC (3-49% mortality). Prosper FX and Helix XTra provided the highest mortality in dry soil at 30ºC (31-49% mortality). Feeding damage by striped flea beetles increased rapidly with higher temperatures. In the 2011 and 2012 bioassays, feeding damage to the cotyledons of check plants in wet and dry soil was lowest at 10ºC (5-8% damage), moderate at 20ºC (12-27% damage) and highest at 30ºC (31-75% damage). Damage at 30ºC was higher in dry soil (60-75% damage) than in wet soil (31-60% damage). Neonicotinoid seed treatments provided poor protection against feeding damage by striped flea beetles in wet soil at 20ºC (10-21% damage) and 30ºC (18-51% damage) and in dry soil at 20ºC (6-15% damage) and 30ºC (12-51% damage). Prosper FX and Helix XTra provided the best protection in dry soil at 20ºC (6-11% damage) and 30ºC (12-15% damage) and wet soil at 30ºC (18-34% damage). The results suggest that seed treatments failures with neonicotinoids are likely when striped flea beetles are present in damaging numbers and temperatures reach or exceed 20ºC. Seed treatment failures are more likely in wet years when precipitation is above-average than in dry years when precipitation is below-average.

In the 2011 bioassays, Fortenza, EX 1 and the Lumiderm/Prosper mixture provided the best control of striped flea beetles in wet soil at 30ºC (20-28% mortality) and dry soil at 30ºC (32-64% mortality). The treatments also provided the best protection against feeding damage in dry soil at 20ºC (9-13% damage) and wet soil at 20ºC (6-12% damage). EX 1 and the Lumiderm/Prosper mixture provided the best protection in wet soil at 30ºC (21-28% damage) and dry soil at 30ºC (8-20% damage). In the 2012 bioassays, EX 1, EX 2 and the Fortenza/Helix XTra mixture provided the best control of striped flea beetles in dry soil at 20ºC (21-23% mortality), wet soil at 30ºC (11-14% mortality) and dry soil at 30ºC (62-81% mortality). The treatments provided the best protection in wet soil at 20ºC (7-9% damage), dry soil at 20ºC (6-8% damage), wet soil at 30ºC (15-20% damage) and dry soil at 30ºC (7-8% damage). Reductions in damage suggest that the treatments may not control the beetles within 72 h but rather inhibit their feeding activity. With better protection against feeding damage, EX 1, EX 2, Fortenza and Fortenza/Helix XTra improved seedling weights in dry and wet soil by 1.2-1.4 times at 20ºC, by 1.4-2.1 times in wet soil at 30ºC and by 2.4-3.7 times in dry soil at 30ºC.

Field trials

In field trials, the efficacy of seed treatments against flea beetles was assessed in relation to feeding damage after 14 and 21 days, stand establishment after 21 days, shoot biomass after 28 days and seed yield. In the 2013 tests, flea beetle counts on sticky traps indicated that relatively low populations of crucifer and striped flea beetles were present during seedling emergence and stand establishment. Based on feeding damage and improvements in stand establishment, biomass and seed yield, the Lumiderm/Helix XTra mixture, Fortenza/Helix XTra mixture, Lumiderm/Prosper mixture along with Prosper Evergol and Helix XTra had the highest efficacy rankings in tests on RR canola, CL canola and canola mustard. In the 2014 tests, sticky cards indicated that high populations of crucifer and particularly striped flea beetles were present during emergence and establishment. The Fortenza/Helix XTra mixture, Prosper Evergol, EX 2 and Helix XTra had the highest efficacy rankings in RR canola. Fortenza, Fortenza/Helix XTra mixture, Helix XTra, Gaucho CS FL and Prosper Evergol had the highest rankings in canola mustard. In the 2015 tests, sticky cards indicated that very high populations of striped flea beetles were present during emergence and establishment. Prosper Evergol, Fortenza/Helix XTra mixture, Fortenza, Fortenza/Helix mixture and EX 2 had the highest efficacy rankings in RR canola. EX 2, Fortenza/Helix XTra mixture, Fortenza/Helix mixture, Prosper Evergol and Fortenza had the highest rankings in CL canola.

Species shift and seed treatment selection

In recent years, there has been a drastic shift in the geographic distribution crucifer and striped flea beetles in Saskatchewan. Before 2010, the crucifer flea beetle was the predominant species in southern and central regions of canola production whereas the striped flea beetle was the most common species in northern parkland and boreal regions. However, since 2010, the geographic range of striped flea beetles has expanded south. At AAFC-Saskatoon, crucifer flea beetles were the most abundant species before 2010 when they comprised 90-95% of the total flea beetle population. Since 2010 populations of striped flea beetles have increased annually until 2015 when they comprised over 90% of the total flea beetle population.

In lab bioassays, Helix, Prosper and Helix XTra provided excellent control and protection against crucifer flea beetles in dry soil at 10, 20 and 30ºC. Prosper and Helix XTra provided the best control and protection against crucifer flea beetles in wet soil at 20 and 30ºC. For canola producers in regions where crucifer flea beetles are the most abundant species, Helix, Prosper and Helix XTra would be an appropriate seed treatment in drier regions whereas Prosper and Helix XTra would be more appropriate in wetter regions. Although Helix is not available commercially, its use would lower production costs and reduce the insecticide load by 50% compared to Helix XTra. With concerns about the accumulation of neonicotinoid in prairie lowlands (Main et al. 2011), use of Helix would be an important step towards reducing environmental contamination. Fortenza could also be used as a substitute for neonicotinoids in control of crucifer flea beetles. Diamide/neonicotinoid mixtures also provided effective control and protection against crucifer flea beetles. However, compared to neonicotinoids, use of the mixtures against crucifer flea beetle is difficult to justify given their higher cost and insecticide load on the environment.

In lab bioassays, newly registered seed treatments including Fortenza, Lumiderm/Prosper mixture, Lumiderm/Helix XTra mixture and Fortenza/Helix XTra mixture provided better control and protection against striped flea beetles, particularly in wet soil. For producers in regions where striped flea beetles are the most abundant species, the new seed treatments are an appropriate option. However, higher production costs and pesticide load with the diamide/neonicotinoid mixtures should be a source of concern. In 2015, when populations of striped flea beetles reached record levels at AAFC-Saskatoon, a mixture containing Fortenza/Helix (200g rate) was as effective against striped and crucifer flea beetles as a mixture of Fortenza/Helix XTra (400g rate). If the application rate of neonicotinoids in the mixtures can be reduced by 50% without compromising efficacy then the high rate in current mixtures is unnecessary and cannot be justified. With the shift in flea beetle populations in Saskatchewan in recent years, canola producers are encouraged to monitor spring and fall populations of flea beetles with sticky traps to identify what species are present and to select the most appropriate seed treatment.

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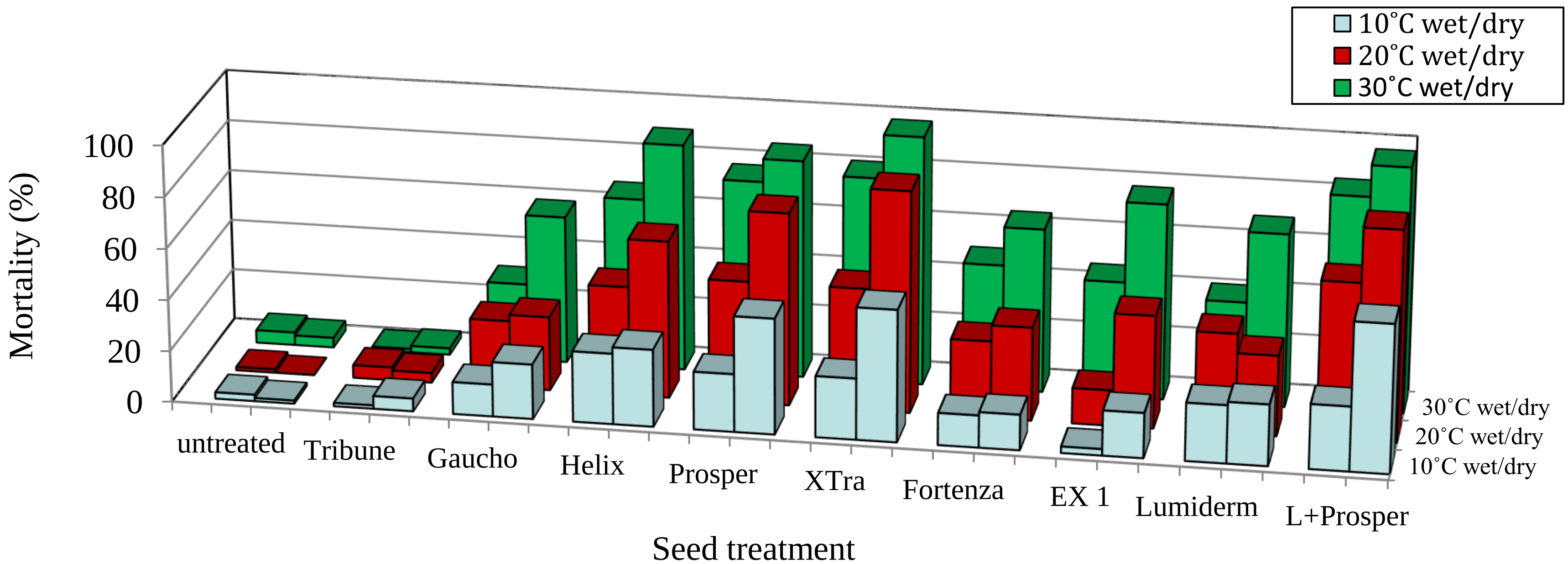
Table 1. Sources of variation in flea beetle mortality, feeding damage and fresh weight of canola seedlings in laboratory assays on crucifer flea beetles, *P. cruciferae*, and striped flea beetles, *P. striolata*, in 2011. [1]

			P. cruciferae (mean)				*P. striolata* (mean)			
Source of variation		d.f.	Mortality 72h (%)	Damage 24h (%)	Damage 72h (%)	Weight 72h (mg)	Mortality 72h (%)	Damage 24h (%)	Damage 72h (%)	Weight 72h (mg)
Temperature (T)	10 °C		20.9a	3.2a	4.0a	156.5a	7.6a	3.1a	4.9a	133.7ab
	20 °C		38.1b	4.5b	7.1b	218.7b	7.9a	6.3b	15.3b	147.4b
	30 °C		55.7c	7.5c	12.7c	206.6b	21.6b	15.0c	34.5c	103.7a
	F-value	2	108.8***	117.1***	98.9***	15.7**	11.3**	78.3***	28.4***	4.3NS
Seed treatment (ST)	untreated		2.3a	9.5a	17.2a	160.4a	2.9a	14.4b	29.4a	113.7ab
	Tribune		3.1a	10.0a	18.9a	160.7a	2.9a	16.1a	30.5a	105.8a
	Gaucho CS FL		29.4b	3.7c-e	4.9c-e	194.3bc	6.5a	5.9de	16.8cd	125.8cd
	Helix		52.7d	3.9cd	5.5cd	191.8b	10.6b	9.0c	21.7b	121.9bc
	Prosper FX (P)		58.5d	3.3e	4.3e	204.5cd	13.8b	6.0de	13.9cd	125.6cd
	Helix XTra		64.3e	3.4de	4.4de	195.6bc	15.8b	6.7d	14.3cd	131.0c-e
	Fortenza		34.2bc	4.1c	5.6c	213.9d	16.0b	5.8de	15.6cd	139.8e
	EX1		33.1bc	5.5b	9.1b	195.7bc	26.5c	5.2e	9.5e	151.5f
	Lumiderm (L)		37.3c	3.9c	5.7c	207.0d	12.5b	6.4de	17.8c	134.0de
	L + P mix		67.7e	3.4de	4.0e	215.1d	16.3b	5.9de	13.4cd	133.5de
	F-value	9	87.7***	101.5***	84.6***	21.5***	17.1***	30.0***	19.4***	12.3***
T x ST interaction	F-value	18	4.8***	24.7***	23.2***	6.2***	3.1***	13.3***	7.8***	5.5***
Moisture (M)	dry		45.1b	5.0a	8.1a	159.9a	16.5b	7.6a	16.6a	106.2a
	wet		31.4a	5.1a	7.8a	228.0b	8.3a	8.7b	19.9b	150.3b
	F-value	1	94.5***	1.9NS	0.1NS	675.4***	65.6***	16.9***	17.7***	194.0***
M x T interaction	F-value	2	1.4NS	0.2NS	0.5NS	44.9***	8.8***	2.0NS	7.7***	4.6*
M x ST interaction	F-value	9	5.9***	3.6***	2.3*	1.7NS	5.7***	4.6***	5.4***	1.0NS
M x T x ST interaction	F-value	18	1.3NS	2.2**	1.5NS	0.7NS	0.7NS	2.5**	2.2**	0.4NS

[1] Means in each column followed by the same letter are not significantly different (ANOVA, P = 0.05). Mortality data and feeding damage were transformed (arcsine square root) before analysis. Untransformed data are shown. *, **, *** F-value significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

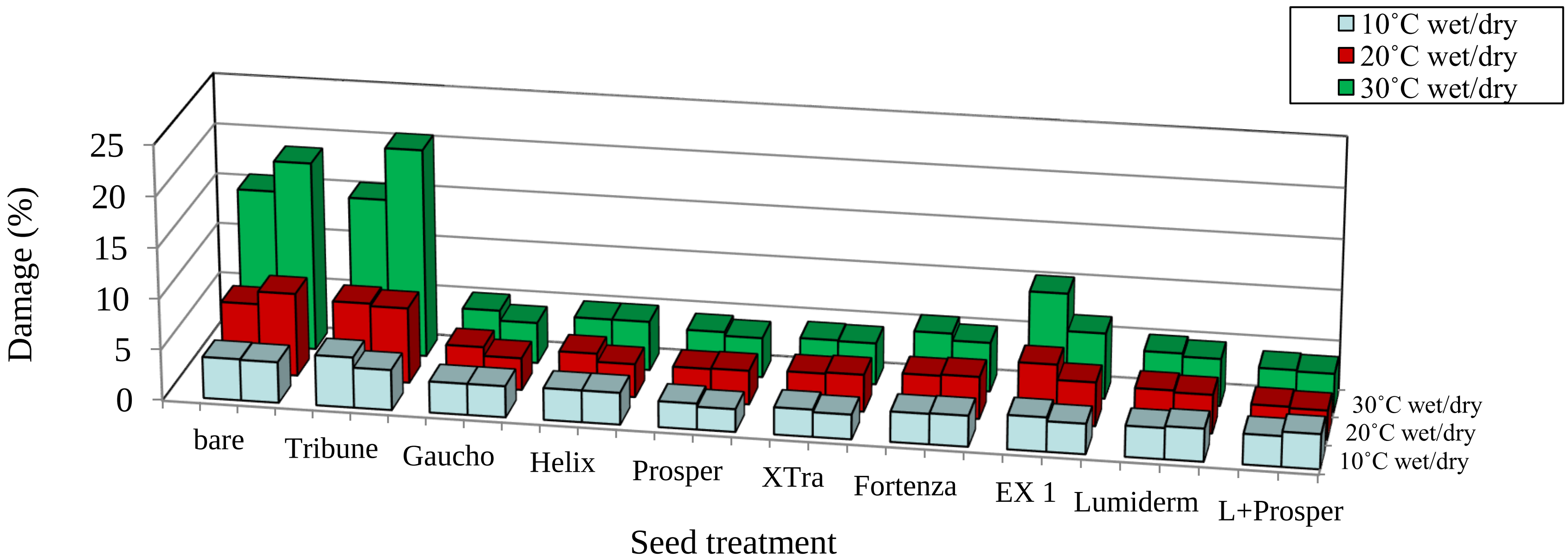
Figure 1. Mortality of crucifer flea beetles exposed to canola seedlings grown with different seed treatments in wet soil or dry soil at 10, 20 and 30°C in 2011. Mortality was assessed after 72 hours. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	2.5ab	1.3a	1.3a	0.0a	5.0a	3.8a
Tribune	1.2a	5.0ab	5.0ab	3.8a	1.3a	2.5a
Gaucho CS FL	12.5bc	21.3c	26.3c	28.8b	30.0b	57.5b
Helix	27.5e	30.0cd	42.5de	61.3cd	66.3cd	88.5de
Prosper FX	22.5c-e	45.0de	47.5e	75.0de	76.0d	85.0d
Helix XTra	23.8de	51.3e	47.5e	86.3e	80.0d	97.0e
Fortenza	12.5cd	13.8bc	30.0cd	36.3b	48.8bc	63.8bc
EX 1	2.5a	17.5c	13.8b	43.8bc	45.0bc	76.3cd
Lumiderm (L)	22.5c-e	23.8c	38.8de	31.3b	40.0b	67.5bc
L + Prosper mix	25.0de	57.5e	61.3f	82.5e	83.8d	96.0e

[1] Means (% mortality) in each column followed by the same letter are not significantly different (Waller-Duncan k-ratio test; k = 100).

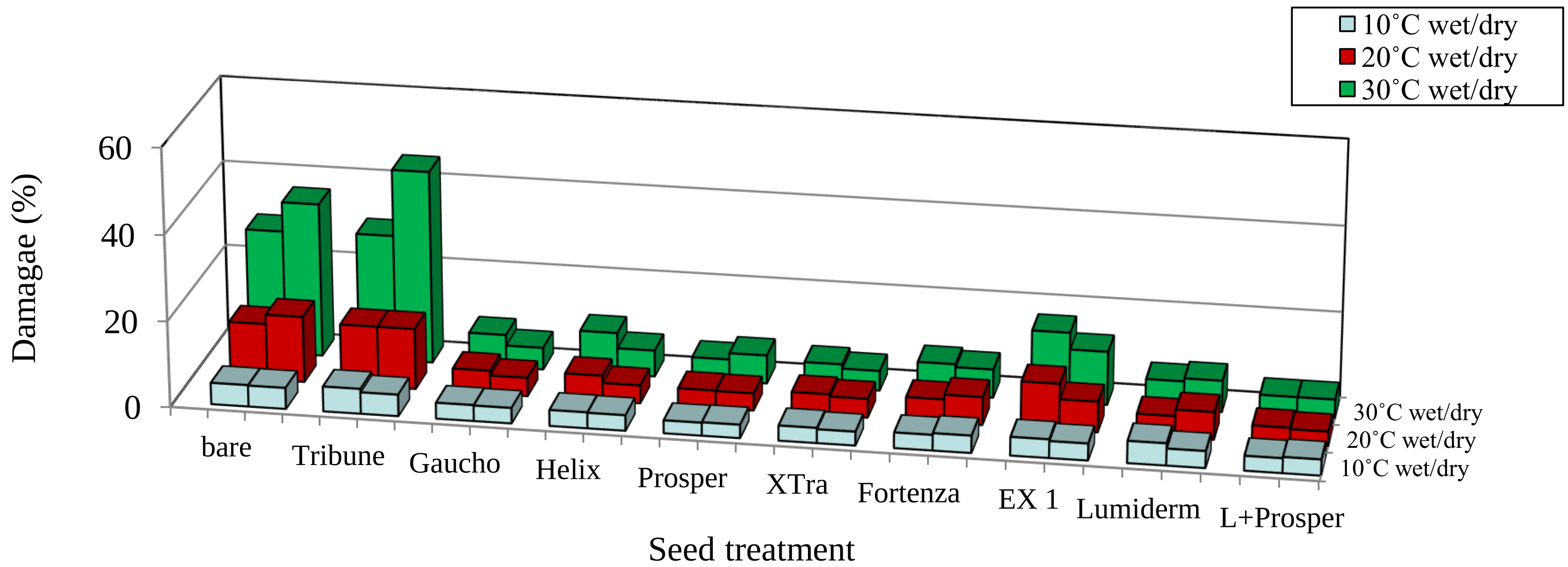
Fig. 2. Feeding damage to canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 24 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	4.1b	4.0a	6.9a	8.1a	15.6a	18.6a
Tribune	4.9a	3.9ab	7.6a	7.4a	15.4a	20.5a
Gaucho CS FL	3.1cd	3.1a-d	4.0c	3.1ef	5.0c	4.0c
Helix	3.1cd	3.1a-d	4.1c	3.3d-f	4.8c	4.8bc
Prosper FX	2.6d	2.3d	3.3d	3.3d-f	4.3c	3.9c
Helix XTra	2.7cd	2.4cd	3.5cd	3.6c-e	4.1c	4.1c
Fortenza	3.0cd	3.1a-d	4.0c	4.1bc	5.5c	4.8bc
EX 1	3.4bc	3.0b-d	5.8b	4.3b	10.1b	6.4b
Lumiderm (L)	3.1cd	3.3a-c	4.0c	3.8b-d	4.9c	4.6bc
L + Prosper mix	3.0cd	3.4ab	3.1d	3.0f	4.0c	3.9c

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

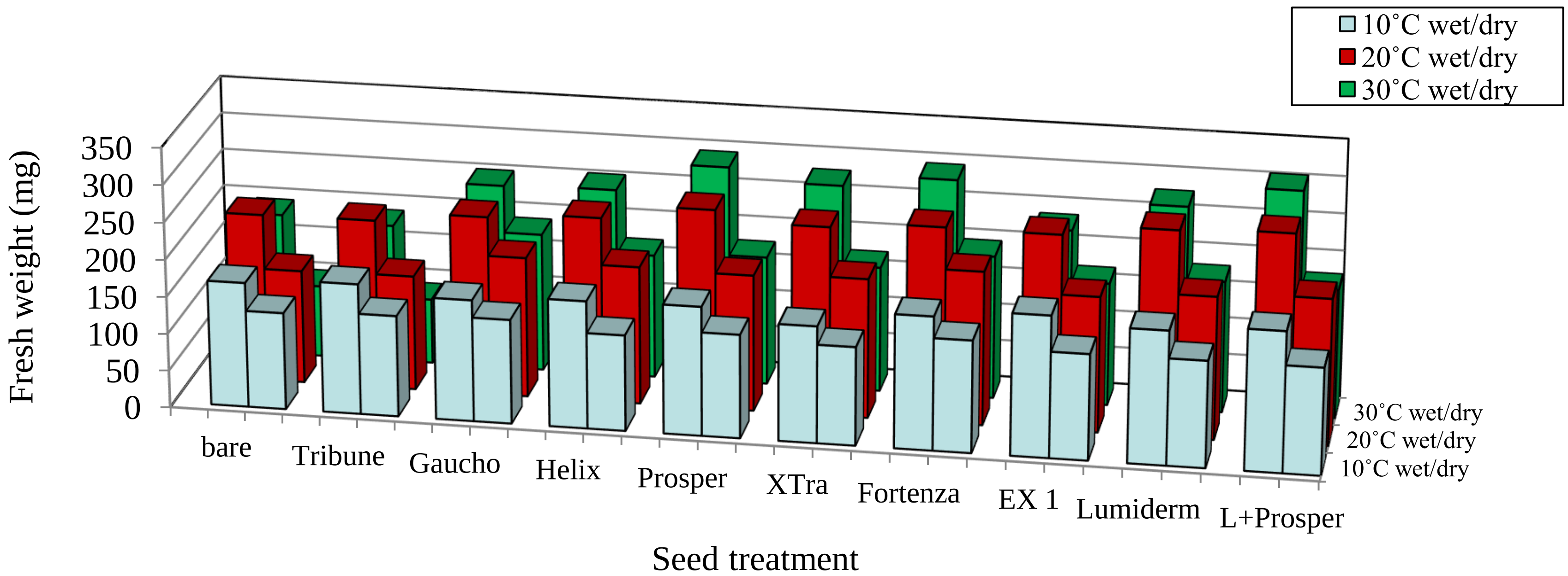
Fig. 3. Feeding damage to canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	5.0ab	4.9a	13.1a	15.3a	28.9a	35.8a
Tribune	5.8a	5.0a	14.1a	14.1a	29.4a	44.9a
Gaucho CS FL	3.7bc	3.6b-d	5.4c	4.3cd	7.6cd	5.1bc
Helix	3.7bc	3.6b-d	5.9c	4.2d	9.7c	6.1bc
Prosper FX	3.0c	3.1d	4.1de	4.0d	5.1de	6.6bc
Helix XTra	3.5bc	3.2cd	4.9cd	4.4cd	5.6de	4.6c
Fortenza	3.6bc	4.0b	5.4c	6.5bc	7.3cd	6.6bc
EX 1	4.3a-c	3.9bc	10.7b	7.1b	16.3b	12.4b
Lumiderm (L)	5.1ab	3.9b	4.9cd	6.4bc	6.6c-e	7.3bc
L + Prosper mix	3.4bc	3.7b-d	3.9e	3.6d	4.6e	4.6c

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

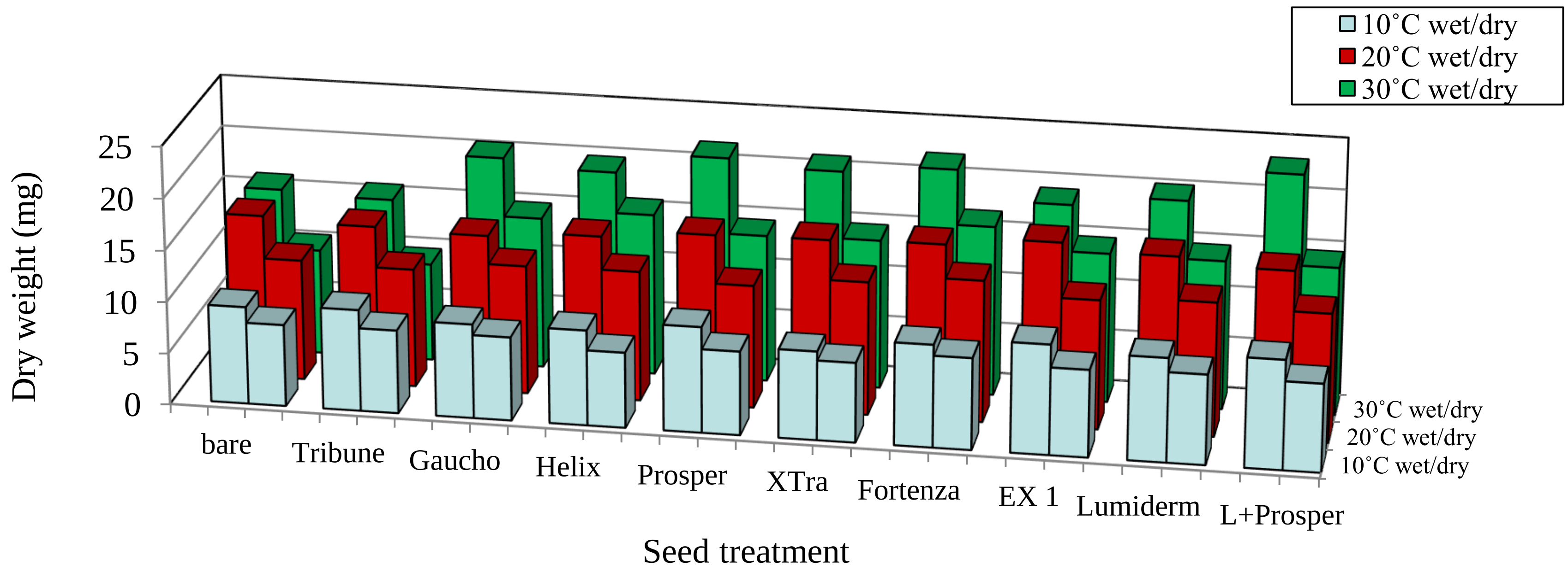
Fig. 4. Fresh weight of canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



	10°C		20°C		30°C	
Treatment	wet	dry	wet	dry	wet	dry
bare	167.9ab	130.2a	225.2a	151.9a	191.2a	96.1a
Tribune	175.4ab	135.7a	226.6a	153.9a	185.4a	87.1a
Gaucho CS FL	163.3ab	140.0a	240.2ab	188.1c	248.9b	185.3bc
Helix	171.3ab	128.7a	248.0ab	184.9c	252.0bc	166.0bc
Prosper FX	173.4ab	139.1a	267.8ab	182.9bc	291.6de	172.5bc
Helix XTra	156.7a	132.2a	253.9ab	187.4c	275.6cd	167.8bc
Fortenza	179.3ab	150.6a	262.7ab	206.6c	292.0de	192.0c
EX 1	190.0b	142.1a	261.9ab	182.3a-c	233.3b	164.8b
Lumiderm (L)	179.6ab	142.9a	277.0b	191.8c	274.2cd	176.5bc
L + Prosper mix	188.4ab	143.3a	281.8b	198.4c	304.3e	174.5bc

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Fig. 5. Dry weight of canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	9.4ab	7.9a	15.8a	11.7a	16.0a	10.2a
Tribune	9.8ab	8.1a	15.4a	11.5a	15.6a	9.4a
Gaucho CS FL	9.1ab	8.1a	15.2a	12.4a	20.3bc	14.6b
Helix	9.2ab	7.3a	15.8a	12.6a	19.6bc	15.6bc
Prosper FX	10.2b	8.1a	16.6a	11.9a	21.6cd	14.2b
Helix XTra	8.6a	7.7a	16.7a	12.9a	20.9b-d	14.4b
Fortenza	9.9ab	8.9a	17.0a	13.7a	21.7cd	16.4c
EX 1	10.6b	8.4a	17.8a	12.5a	19.0b	14.5b
Lumiderm (L)	10.0ab	8.7a	17.1a	13.0a	20.0bc	14.4b
L + Prosper mix	10.5b	8.5a	16.4a	12.6a	23.2d	14.4b

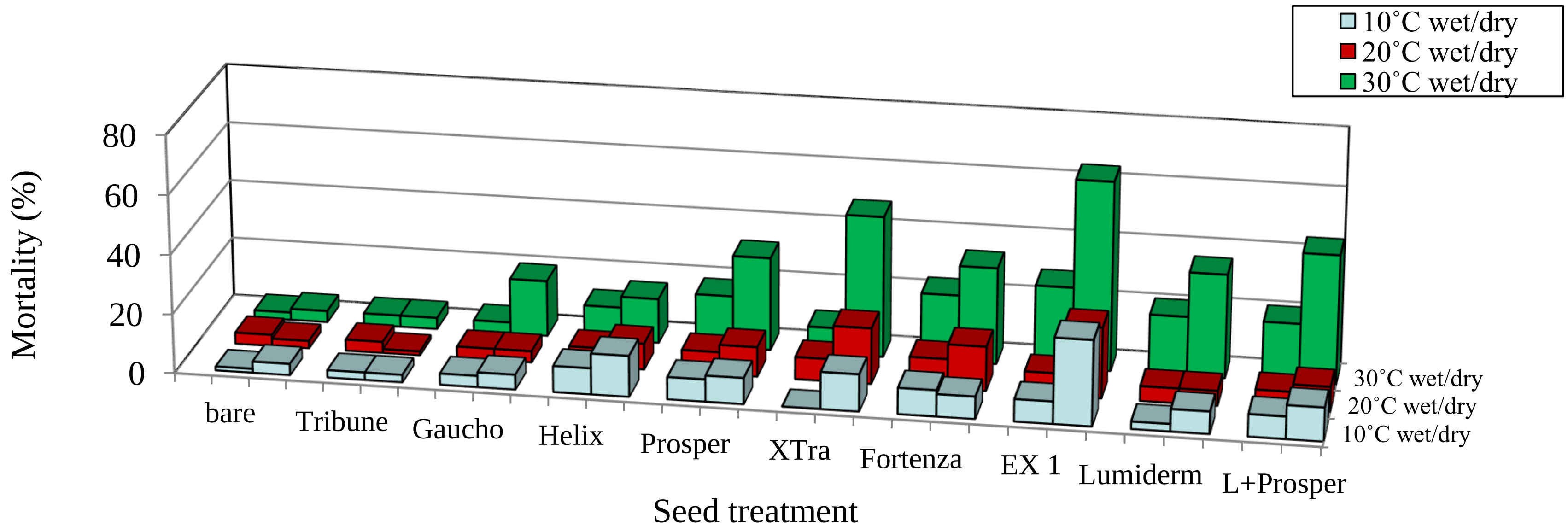
[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Table 2. Ranking of seed treatments in bioassays on crucifer flea beetles in wet and dry soil in 2011. [1]

Treatment	Control (% mortality)		Protection (damage 24/72h)		Shoot weight (mg)		Overall	
	wet	dry	wet	dry	wet	dry	wet	dry
bare	9	10	9	10	9	9	9	10
Tribune	9	9	10	9	9	9	10	9
Gaucho CS FL	7	7	4	4	8	2	7	5
Helix	3	4	7	5	6	2	6	3
Prosper FX	3	3	1	1	2	7	2	3
Helix XTra	2	1	3	2	5	2	3	1
Fortenza	6	7	4	6	2	1	4	6
EX 1	8	5	8	8	6	8	8	8
Lumiderm (L)	5	6	4	6	4	2	5	6
L + Prosper mix	1	1	1	2	1	2	1	1

[1] Rankings based on Waller-Duncan comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values.

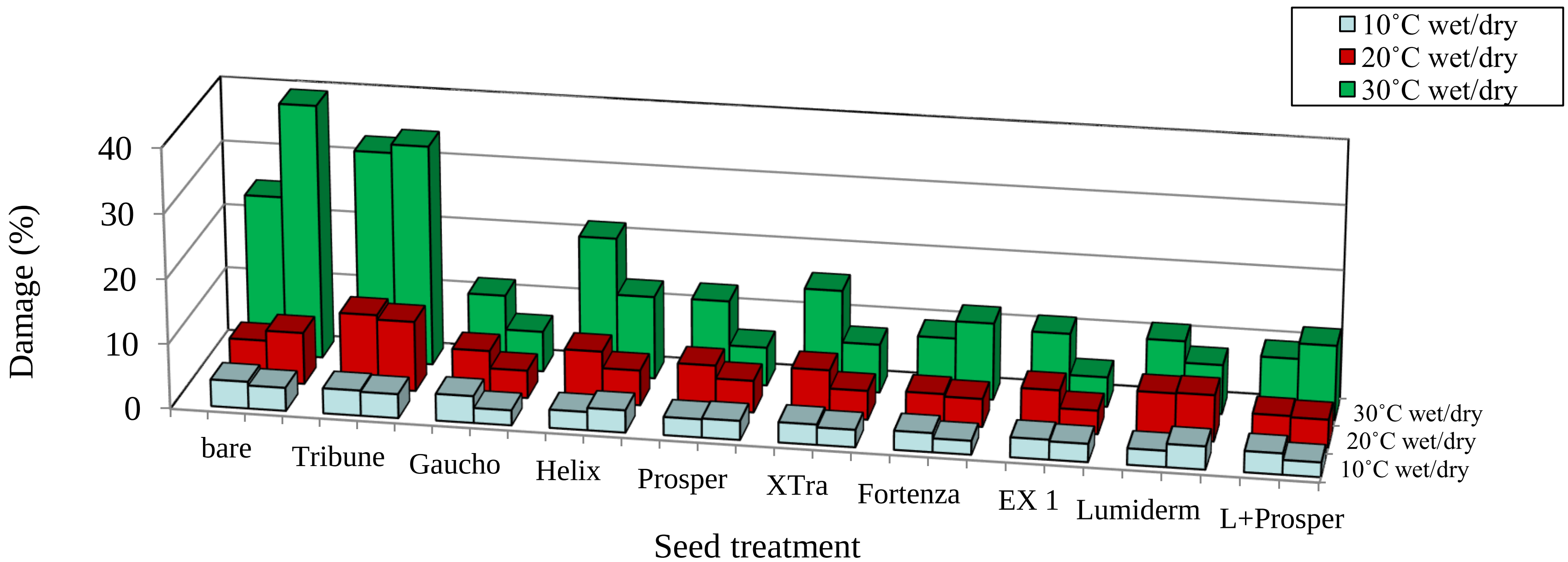
Fig. 6. Mortality of striped flea beetles exposed to canola seedlings grown with different seed treatments in wet soil or dry soil at 10, 20 and 30°C in 2011. Mortality was assessed after 72 hours. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	1.3ab	3.8ab	3.8a	2.5ab	2.5a	3.8a
Tribune	2.5ab	2.5a	3.8a	1.3a	3.8ab	3.8a
Gaucho CS FL	3.8a-c	5.0a-c	3.8a	3.8a-c	3.8a	18.8bc
Helix	8.8c	13.8d	6.3a	8.8b-e	11.3a-c	15.0ab
Prosper FX	7.5bc	8.8a-d	7.5a	10.0c-e	17.5b-d	31.3b-d
Helix XTra	0.0a	12.5cd	7.5a	18.8ef	8.8a-c	47.5de
Fortenza	8.8bc	7.5a-d	10.0a	15.0d-f	22.5cd	32.5b-d
EX 1	7.5bc	28.8e	7.5a	23.8f	27.5d	63.8e
Lumiderm (L)	2.5a-c	7.5a-d	5.0a	5.0a-c	20.0cd	35.0cd
L + Prosper mix	7.5bc	11.3b-d	6.3a	8.8b-d	20.0cd	43.8d

[1] Means (% mortality) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

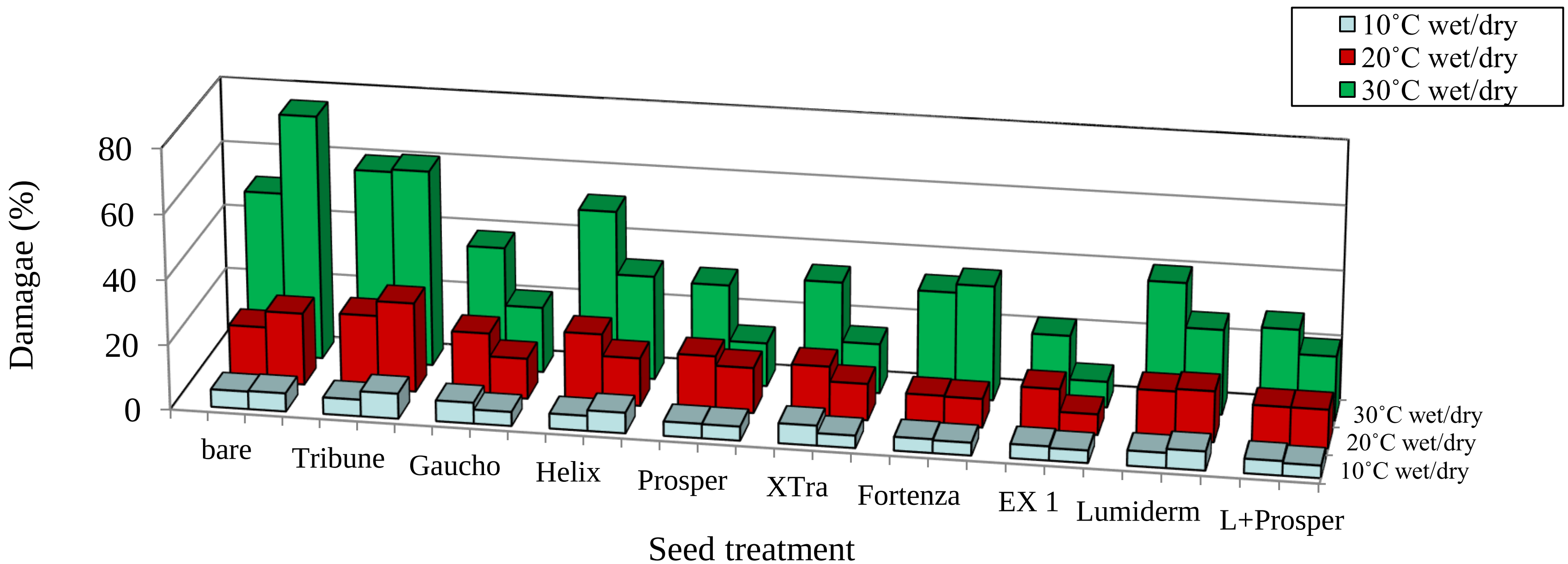
Fig.7. Feeding damage to canola seedlings grown with different seed treatments and exposed to striped flea beetles for 24 h in wet and dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	4.1a	3.6a	6.4b	7.9ab	24.8b	39.3a
Tribune	3.9ab	3.7a	11.4a	10.8a	32.7a	34.0a
Gaucho CS FL	4.1ab	2.3a	6.9b	4.3cd	11.5cd	6.2bc
Helix	2.8bc	3.4a	7.9ab	5.4b-d	21.4b	12.7b
Prosper FX	2.8bc	2.9a	6.9b	4.9cd	12.8cd	5.9bc
Helix XTra	3.1a-c	2.7a	7.3b	4.4cd	15.4c	7.4bc
Fortenza	2.9a-c	2.1a	4.7b	4.3cd	9.1d	11.8b
EX 1	3.1a-c	2.8a	6.4b	3.6d	10.9cd	4.6c
Lumiderm (L)	2.5c	3.6a	7.0b	7.1bc	10.9cd	7.6bc
L + Prosper mix	3.3a-c	2.3a	4.7b	4.5cd	9.3d	11.6b

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

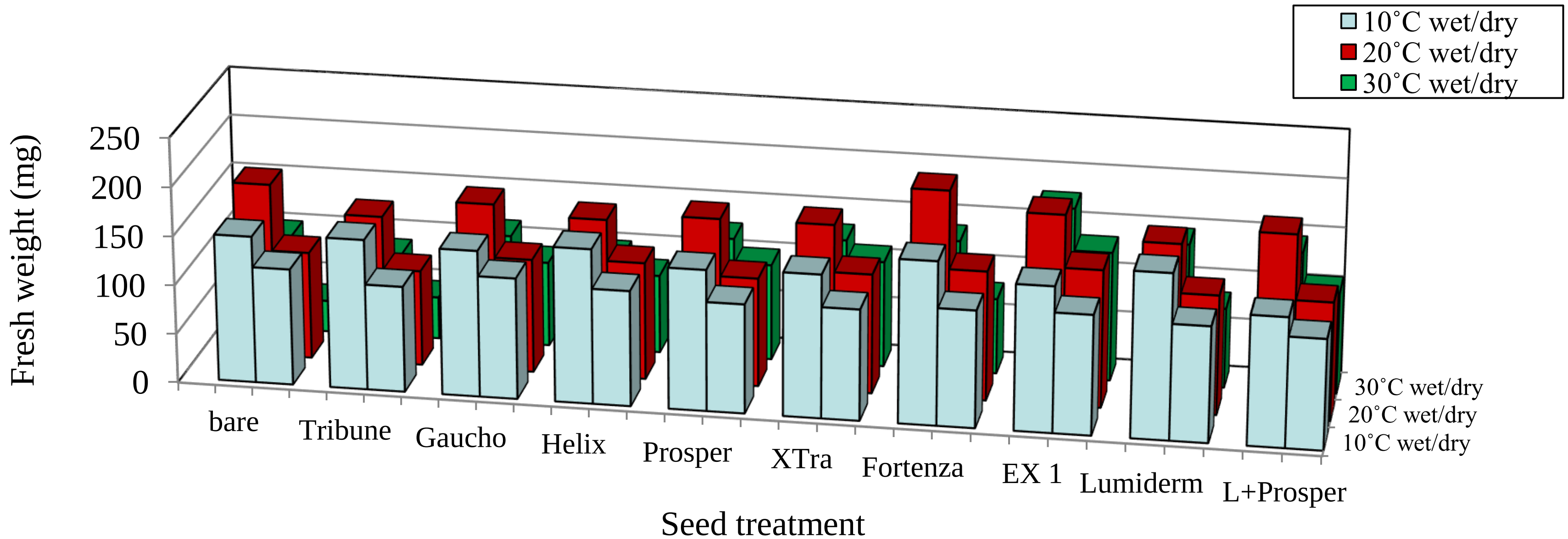
Fig. 8. Feeding damage to canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet and dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	5.4a	5.6ab	17.1a-d	22.1ab	50.9ab	75.4a
Tribune	5.1a	7.7a	22.8a	27.4a	59.6a	60.3b
Gaucho CS FL	6.4a	4.3b	19.5a-c	12.4cd	38.0bc	20.1ce
Helix	4.6a	6.3ab	21.4ab	14.7bc	51.3ab	31.9c
Prosper FX	4.4a	4.3b	16.8b-d	13.9bc	30.6cd	13.3de
Helix XTra	6.1a	3.8b	15.8cd	11.2cd	33.6cd	15.2de
Fortenza	4.2a	3.9b	9.0e	8.8cd	32.6cd	35.2c
EX 1	4.3a	3.8b	13.3de	6.3d	21.4d	7.9e
Lumiderm (L)	4.6a	5.8ab	14.8cd	15.6bc	39.8bc	26.1cd
L + Prosper mix	4.4a	3.8b	12.2de	12.2cd	27.6cd	20.1c-e

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

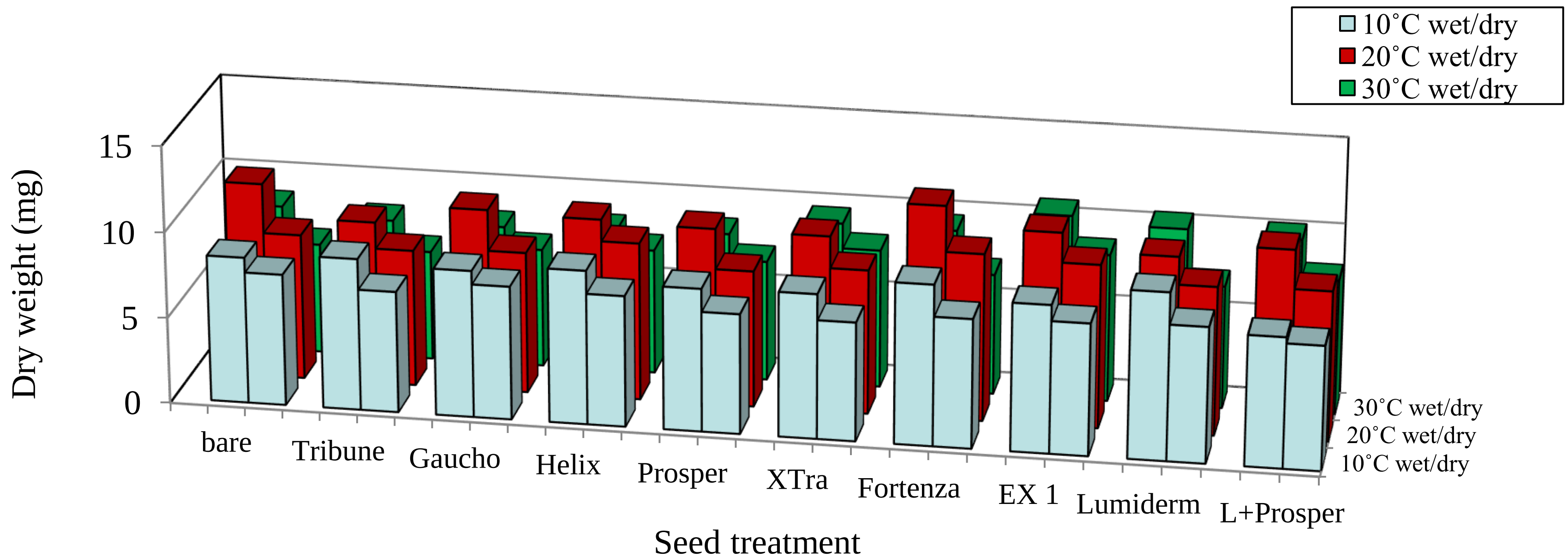
Fig. 9. Fresh weight of canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	149.3b	118.2a	176.6bc	108.7ab	97.2ab	31.9a
Tribune	152.9bc	107.5a	150.4a	96.8a	84.6a	42.8a
Gaucho CS FL	148.7b	123.1a	170.0a-c	115.5a-c	111.4a-c	86.0b-d
Helix	157.4bd	117.4a	161.0ab	119.1a-c	96.9ab	79.4b
Prosper FX	143.5ab	111.1a	168.8a-c	110.4ab	122.4b-d	97.5b-d
Helix XTra	145.9ab	113.1a	169.6a-c	121.6a-c	127.9b-d	107.8de
Fortenza	166.3cd	119.3a	211.2d	131.7bc	133.9cd	76.6b
EX 1	148.3b	122.1a	193.5cd	140.1c	174.0e	131.2e
Lumiderm (L)	168.5d	117.9a	171.1a-c	121.6a-c	144.2de	81.0bc
L + Prosper mix	131.8a	112.5a	187.7b-d	121.7a-c	143.3de	104.0cd

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Fig. 10. Dry weight of canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2011. [1]



	10°C		20°C		30°C	
Treatment	wet	dry	wet	dry	wet	dry
bare	8.5ab	7.6a	11.3ab	8.4a	8.5a-c	6.4a
Tribune	8.8bc	7.0a	9.5a	7.9a	8.1a	6.4a
Gaucho CS FL	8.5ab	7.7a	10.6ab	8.2ab	8.1a	6.9ab
Helix	8.9bc	7.6a	10.4a	9.2ab	8.3ab	7.2ab
Prosper FX	8.3ab	7.0a	10.3a	7.9a	8.5a-c	7.0ab
Helix XTra	8.4ab	6.9a	10.2a	8.4ab	9.5a-d	8.0ab
Fortenza	9.4bc	7.5a	12.4b	9.7b	9.5a-d	7.0ab
EX 1	8.6a-c	7.7a	11.2ab	9.5ab	10.7d	8.6b
Lumiderm (L)	9.7c	7.9a	10.2a	8.6ab	10.3cd	7.1ab
L + Prosper mix	7.6a	7.2a	11.0ab	8.8ab	10.1bc	7.9ab

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Table 3. Ranking of seed treatments in bioassays on striped flea beetles in wet and dry soil in 2011. [1]

	Control (% mortality)		Protection (damage 24/72h)		Shoot weight (mg)		Overall	
Treatment	wet	dry	wet	dry	wet	dry	wet	dry
bare	10	9	8	9	7	9	9	9
Tribune	7	10	10	10	10	10	10	10
Gaucho CS FL	7	8	7	3	7	4	7	6
Helix	6	6	8	8	7	8	7	8
Prosper FX	4	5	4	4	5	5	5	4
Helix XTra	7	2	6	2	5	2	6	2
Fortenza	2	3	1	6	1	5	1	4
EX 1	1	1	2	1	2	1	2	1
Lumiderm (L)	4	7	4	7	2	5	4	7
L + Prosper mix	2	4	2	4	4	3	3	3

[1] Rankings based on Waller-Duncan comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values.

Table 4. Spearman-rank correlations between flea beetle mortality with seed treatments in 2011 bioassays and associated feeding damage and plant weights at different moisture regimes and temperatures. [1]

		wet soil			dry soil		
Species	Variable	10°C	20°C	30°C	10°C	20°C	30°C
crucifer	damage - 24h	-0.45**	-0.73***	-0.72***	-0.59***	-0.68***	-0.67***
	- 48h	-0.48**	-0.71***	-0.79***	-0.68***	-0.70***	-0.74***
	- 72h	-0.42**	-0.77***	-0.80***	-0.75***	-0.76***	-0.77***
	fresh weight	0.03NS	0.23NS	0.73***	-0.02NS	0.36*	0.52***
	dry matter	0.04NS	-0.07NS	0.70***	0.01NS	0.16NS	0.50***
striped	damage - 24h	-0.19NS	-0.09NS	-0.18NS	0.16NS	-0.53***	-0.60***
	- 48h	-0.23NS	-0.11NS	-0.09NS	-0.35*	-0.58***	-0.66***
	- 72h	-0.30NS	0.00NS	-0.06NS	-0.31NS	-0.48**	-0.70***
	fresh weight	-0.11NS	0.32*	-0.01NS	-0.09NS	0.05NS	0.66***
	dry matter	-0.12NS	0.25NS	-0.09NS	-0.13NS	0.05NS	0.40**

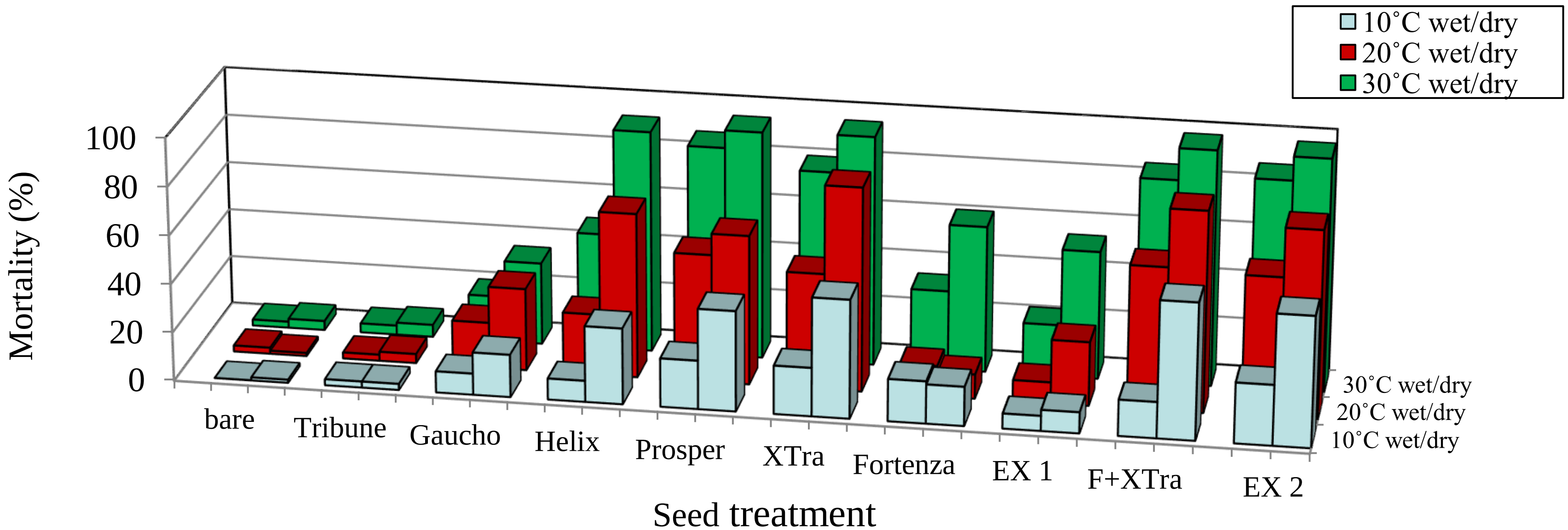
[1] *, **, *** Spearman coefficient (n = 40 values) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 5. Sources of variation in flea beetle mortality, feeding damage and fresh weight of canola seedlings in laboratory assays on crucifer flea beetles, *P. cruciferae*, and striped flea beetles, *P. striolata*, in 2012. [1]

			P. cruciferae (mean)				*P. striolata* (mean)			
Source of variation		d.f.	Mortality 72h (%)	Damage 24h (%)	Damage 72h (%)	Weight 72h (mg)	Mortality 72h (%)	Damage 24h (%)	Damage 72h (%)	Weight 72h (mg)
Temperature (T)	10 °C		20.1a	2.7a	3.5a	181.2a	4.2a	3.3a	5.3a	161.5a
	20 °C		36.7b	3.8b	5.9b	236.3b	8.3b	5.5b	10.8b	195.4b
	30 °C		54.4c	5.7c	12.5c	214.3b	24.2c	11.7c	23.1c	166.3a
	F-value	2	71.2***	26.1**	175.3***	11.4**	196.6***	192.4***	79.6***	7.6*
Seed treatment (ST)	untreated		1.9a	7.9a	15.7b	190.1ab	1.3a	12.5a	24.7a	147.6a
	Tribune		3.3a	8.2a	18.2a	180.0a	1.3a	12.6a	23.8a	154.8ab
	Gaucho CS FL		21.9b	3.1cd	5.0d	198.4b	7.5b	5.6cd	12.0bc	161.5b
	Helix		45.2c	3.1cd	4.6de	222.8c-e	9.2bc	7.1b	13.4b	175.4c
	Prosper FX		59.1d	2.7de	3.8ef	218.1cd	12.3b-d	5.3c-e	9.8c-f	180.4c
	Helix XTra		62.2de	2.8de	3.8ef	226.1c-e	13.8c-e	5.7cd	10.6c-e	177.6c
	Fortenza (F)		24.8b	3.3c	4.8d	215.9c	14.2de	5.8c	11.3b-d	177.3c
	EX		20.6b	4.7b	10.1c	196.5b	20.8fg	4.8c-e	9.0df	180.7c
	F + XTra mix		65.5e	2.6e	3.8f	227.7de	23.3g	4.6de	8.0f	191.6d
	EX + XTra mix		66.0e	2.6e	3.6f	230.1e	18.5ef	4.4e	8.3ef	196.9d
	F-value	9	134.8***	80.7***	135.1***	20.6***	20.0***	42.3***	27.9***	17.7***
T x ST interaction	F-value	18	8.5***	15.9***	39.2***	5.1***	3.2***	14.3***	9.2***	4.0***
Moisture (M)	dry		45.1b	4.0a	7.6NS	160.0a	19.4b	6.6a	13.3a	116.6a
	wet		29.0a	4.2b	7.1NS	261.1b	5.0a	7.0b	12.9a	232.1b
	F-value	1	221.9***	8.5**	0.1NS	1023.5***	165.3***	9.1**	0.7NS	1895.0***
M x T interaction	F-value	2	2.2NS	0.2NS	1.1NS	69.1***	55.4***	1.7NS	0.3NS	92.6***
M x ST interaction	F-value	9	11.4***	6.3***	14.1***	1.4NS	7.5***	7.6***	17.4***	1.5NS
M x T x ST interaction	F-value	18	1.6NS	4.2***	9.4***	0.7NS	2.6**	3.8***	7.0***	0.6NS

[1] Means in each column followed by the same letter are not significantly different (ANOVA, P = 0.05). Mortality data and feeding damage were transformed (arcsine square root) before analysis. Untransformed data are shown. *, **, *** F-value significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

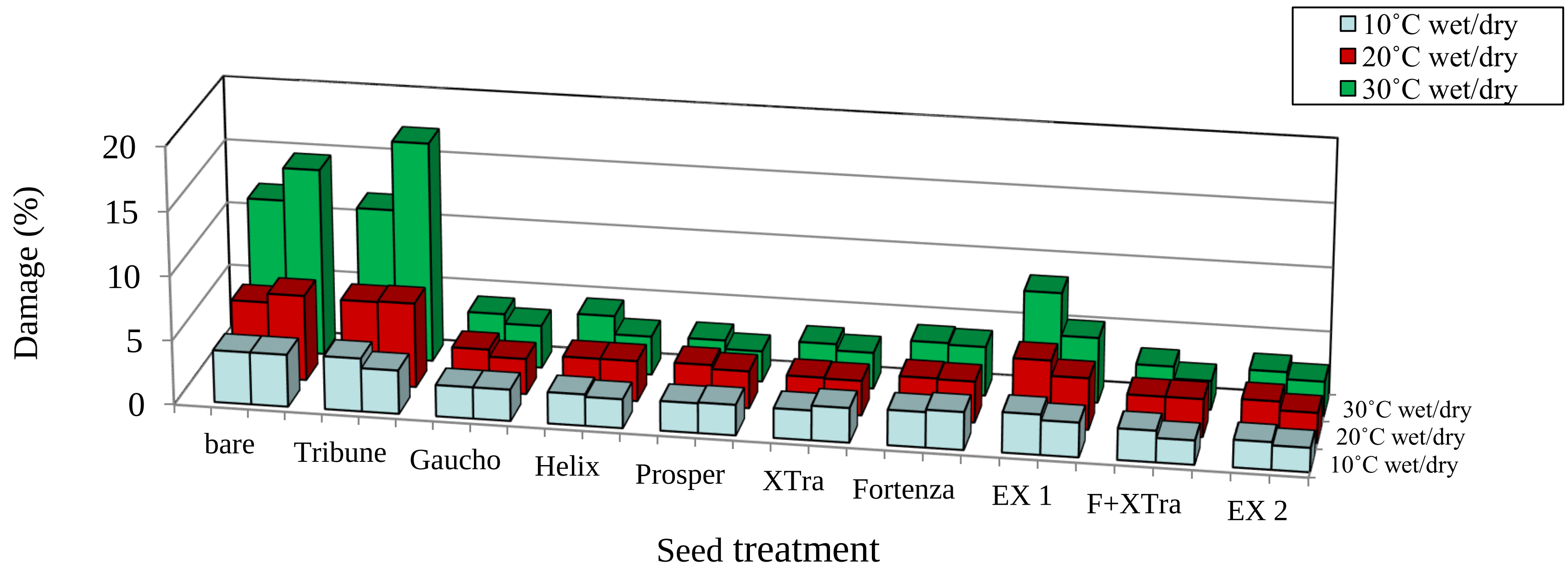
Fig. 11. Mortality of crucifer flea beetles exposed to canola seedlings grown with different seed treatments in wet soil or dry soil at 10, 20 and 30°C in 2012. Mortality was assessed after 72 hours. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	0.0a	1.3a	2.5a	1.3a	2.5a	3.8a
Tribune	2.5ab	2.5ab	2.5a	3.8ab	3.8a	5.0a
Gaucho CS FL	8.8bc	17.5c	18.8bc	33.8c	18.8b	33.8b
Helix	8.8bc	31.3d	25.0c	67.5de	47.5d	91.0d
Prosper FX	20.0cd	41.3de	52.5d	61.3d	86.3e	93.5d
Helix XTra	20.0cd	48.8e	47.5d	83.8f	78.8e	94.3d
Fortenza (F)	17.5cd	16.3c	12.5ab	10.0b	32.5c	60.0c
EX 1	6.3ab	8.8bc	8.8ab	26.3c	21.3bc	52.5c
F + XTra mix	15.0cd	56.3e	58.8d	82.5f	83.8e	96.8d
EX 2	25.0d	53.8e	57.5d	77.5ef	86.3e	96.0d

[1] Means (% mortality) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

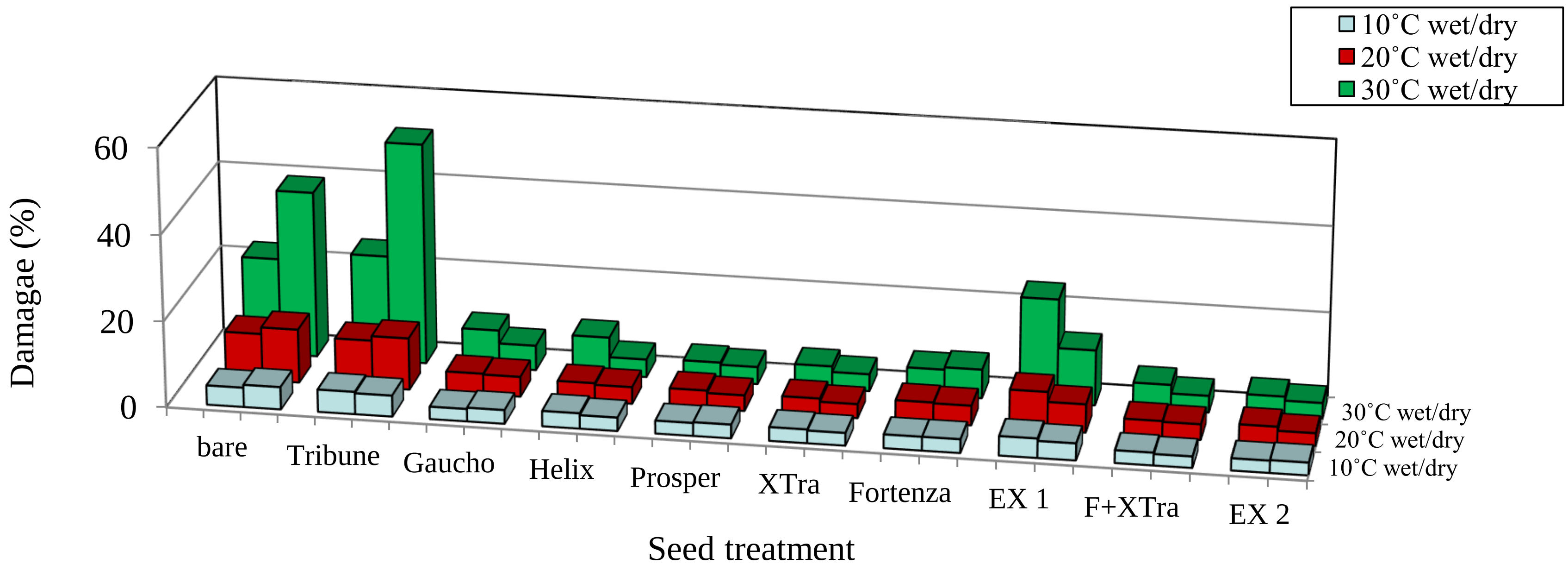
Fig. 12. Feeding damage to canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 24 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	4.1a	4.1a	5.9ab	6.6a	12.0a	14.6b
Tribune	4.1a	3.4ab	6.5a	6.6a	11.8a	17.1a
Gaucho CS FL	2.4bc	2.4b-d	3.3c	2.8cd	4.1c	3.3de
Helix	2.4bc	2.3cd	3.1c	3.1cd	4.4c	3.0de
Prosper FX	2.3c	2.4b-d	3.2c	2.9cd	3.1c	2.4e
Helix XTra	2.3bc	2.7b-d	2.8c	2.7cd	3.3c	2.8de
Fortenza (F)	2.8bc	2.9bc	3.3c	3.2c	3.9c	3.8cd
EX 1	3.1b	2.7b-d	5.2b	4.0b	8.4b	5.1c
F + XTra mix	2.4bc	1.9d	2.9c	2.9cd	3.2c	2.3e
EX 2	2.1c	1.9d	3.1c	2.4d	3.3c	2.8de

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

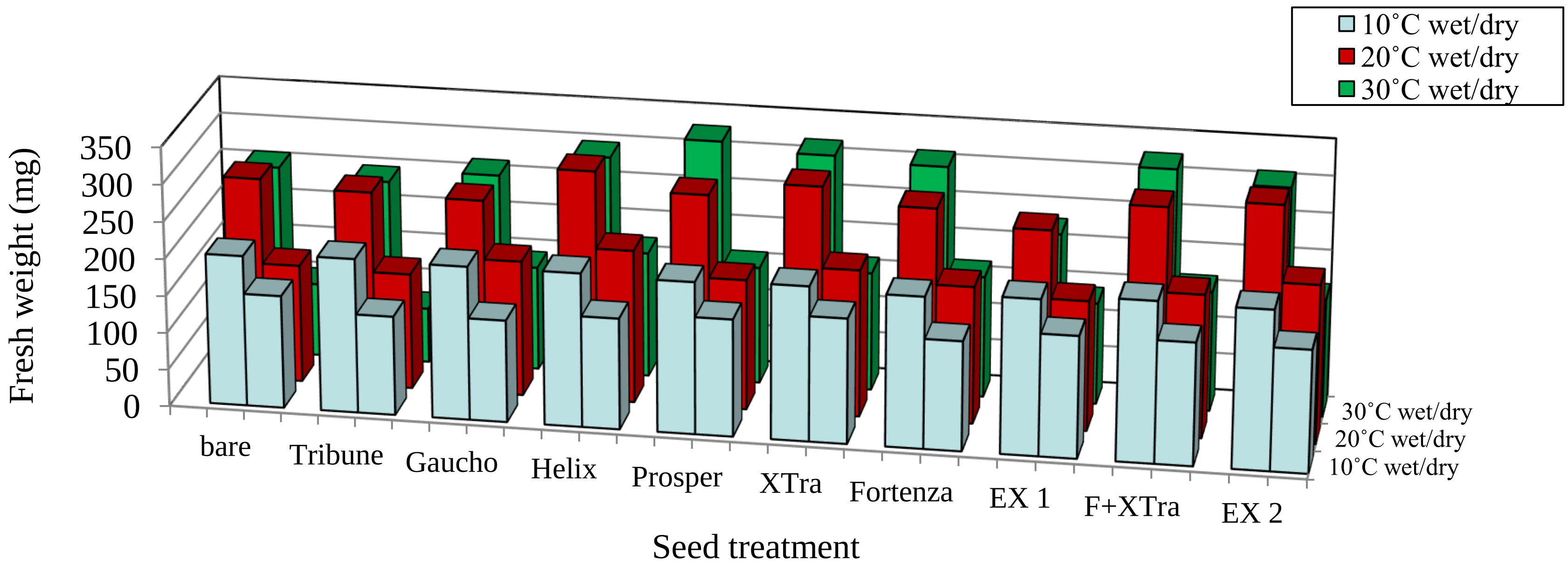
Fig. 13. Feeding damage to canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



	10°C		20°C		30°C	
Treatment	wet	dry	wet	dry	wet	dry
bare	4.5ab	5.2a	10.9a	12.4a	22.5a	38.6b
Tribune	5.2a	4.9a	10.9a	12.0a	24.7a	51.4a
Gaucho CS FL	2.9c	3.2c	4.8c	4.6c	8.8b	5.8d
Helix	3.6bc	3.1c	4.3cd	3.9cd	8.8b	4.1d
Prosper FX	3.0c	3.2c	4.2cd	3.6d	4.5c	4.0d
Helix XTra	3.2c	2.9cd	4.0cd	3.3d	5.3c	3.9d
Fortenza (F)	3.2c	3.2c	4.8c	4.6c	6.1bc	6.7d
EX 1	4.5ab	3.9b	8.9b	6.6b	24.1a	12.8c
F + XTra mix	2.9c	2.6d	3.8d	3.6d	5.9c	3.9d
EX 2	2.8c	2.9cd	4.2cd	3.3d	4.8c	3.9d

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

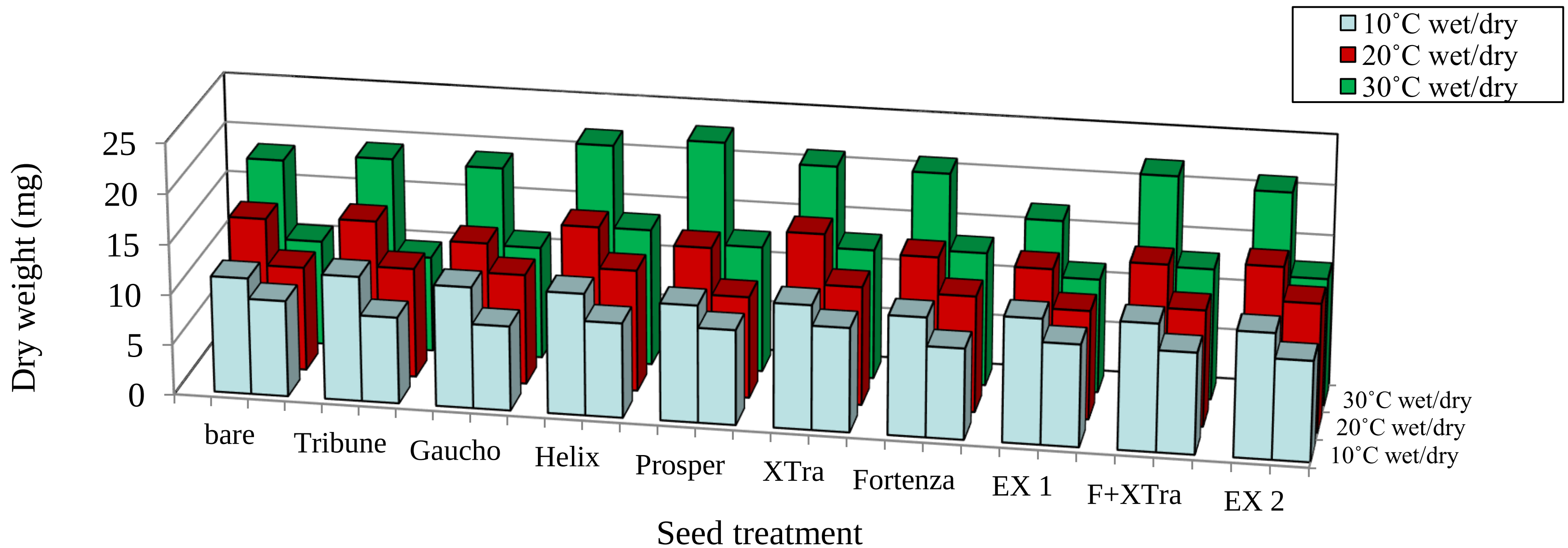
Fig. 14. Fresh weight of canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	203.0a	151.9a-c	273.5ab	158.3a	256.0a	98.1b
Tribune	208.2a	133.4a	264.0a	155.7a	245.1a	73.6a
Gaucho CS FL	207.0a	137.5a	261.8a	182.2bc	262.6ab	139.4c
Helix	207.2a	149.6a-c	309.9c	205.9de	295.8bc	168.1d
Prosper FX	204.8a	157.9bc	287.0a-c	175.5ab	326.0c	157.4d
Helix XTra	208.4a	168.5c	307.1bc	198.0c-e	315.7c	159.2d
Fortenza (F)	203.8a	147.7ab	286.8a-c	184.8b-d	309.2c	163.1d
EX 1	209.8a	164.2bc	266.6a	175.1ab	227.1a	136.4c
F + XTra mix	216.9a	165.0bc	306.5bc	192.9b-e	323.4c	161.6d
EX 2	214.7a	164.9bc	318.3c	215.2e	307.7c	159.9d

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Fig. 15. Dry weight of canola seedlings grown with different seed treatments and exposed to crucifer flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	11.6a	9.5a-c	15.0ab	10.3ab	18.4ab	10.4ab
Tribune	12.4a	8.6ab	15.4ab	10.8a-c	19.2a-c	9.5a
Gaucho CS FL	12.0a	8.4a	13.9a	10.9a-c	18.9a-c	11.1bc
Helix	12.1a	9.4a-c	16.1ab	12.0cd	21.8cd	13.5e
Prosper FX	11.6a	9.4a-c	14.8ab	10.1a	22.7d	12.5c-e
Helix XTra	12.3a	10.3c	16.8b	11.7b-d	21.0b-d	12.9e
Fortenza (F)	11.8a	9.0a-c	15.1ab	11.5a-d	20.9b-d	13.2e
EX 1	12.4a	10.1bc	14.7ab	10.7a-c	16.9a	11.3b-d
F + XTra mix	12.6a	10.0bc	15.8ab	11.5a-d	21.9cd	13.0e
EX 2	12.4a	9.9a-c	16.2ab	12.8d	21.0b-d	12.7de

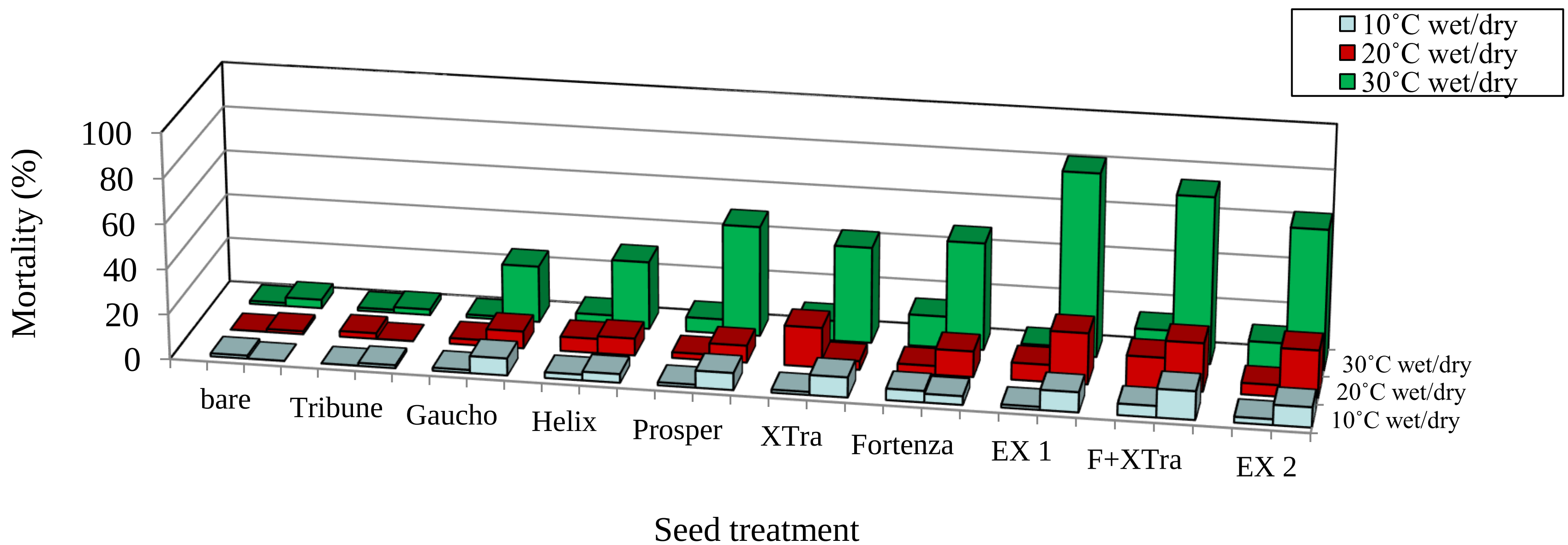
[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Table 6. Ranking of seed treatments in bioassays on crucifer flea beetles in wet and dry soil in 2012. [1]

	Control (% mortality)		Protection (damage 24/72h)		Shoot weight (mg)		Overall	
Treatment	wet	dry	wet	dry	wet	dry	wet	dry
bare	10	10	9	9	7	9	9	9
Tribune	9	9	10	10	9	10	10	10
Gaucho CS FL	7	7	6	6	7	8	7	7
Helix	5	4	6	5	2	3	5	4
Prosper FX	2	4	1	3	5	6	3	5
Helix XTra	2	1	4	3	2	2	3	1
Fortenza (F)	6	7	5	7	5	5	6	6
EX 1	8	6	8	8	9	7	8	7
F + XTra mix	2	1	1	1	2	4	2	1
EX 2	1	3	1	2	1	1	1	1

[1] Rankings based on Waller-Duncan comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values.

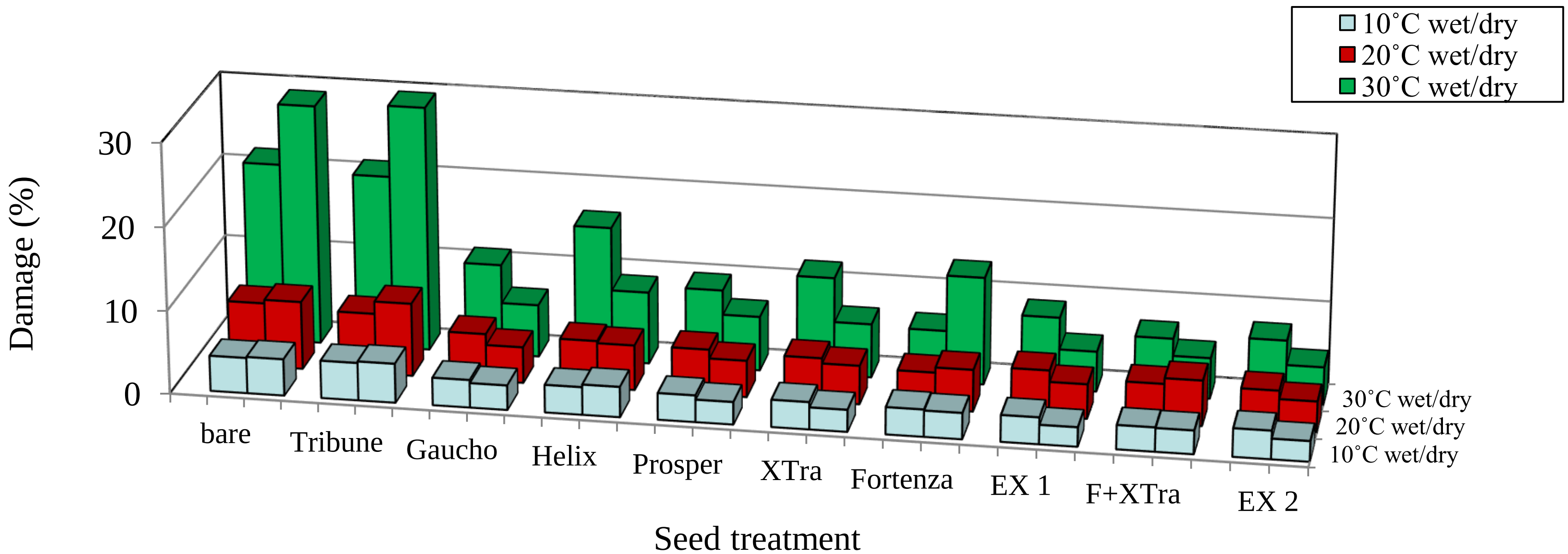
Fig. 16. Mortality of striped flea beetles exposed to canola seedlings grown with different seed treatments in wet soil or dry soil at 10, 20 and 30°C in 2012. Mortality was assessed after 72 hours. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	1.3a	0.0a	0.0a	1.3a	1.3a	3.8a
Tribune	0.0a	1.3ab	2.5a	0.0a	1.3a	2.5a
Gaucho CS FL	1.3a	7.5b-d	2.5a	7.5ab	1.3a	25.0b
Helix	2.5a	3.8a-c	6.3a	7.5ab	5.0ab	30.0bc
Prosper FX	1.3a	7.5b-d	2.5a	7.5a-c	6.3ab	48.8de
Helix XTra	1.3a	8.8cd	17.5a	3.8ab	8.8ab	42.5cd
Fortenza (F)	5.0a	3.8a-d	3.8a	11.3bc	13.8b	47.5d
EX 1	1.3a	8.8cd	7.5a	22.5d	3.8ab	81.3g
F + XTra mix	5.0a	12.5d	13.8a	21.3cd	13.8b	73.8fg
EX 2	2.5a	8.8cd	5.0a	21.3d	11.3ab	62.5ef

[1] Means (% mortality) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

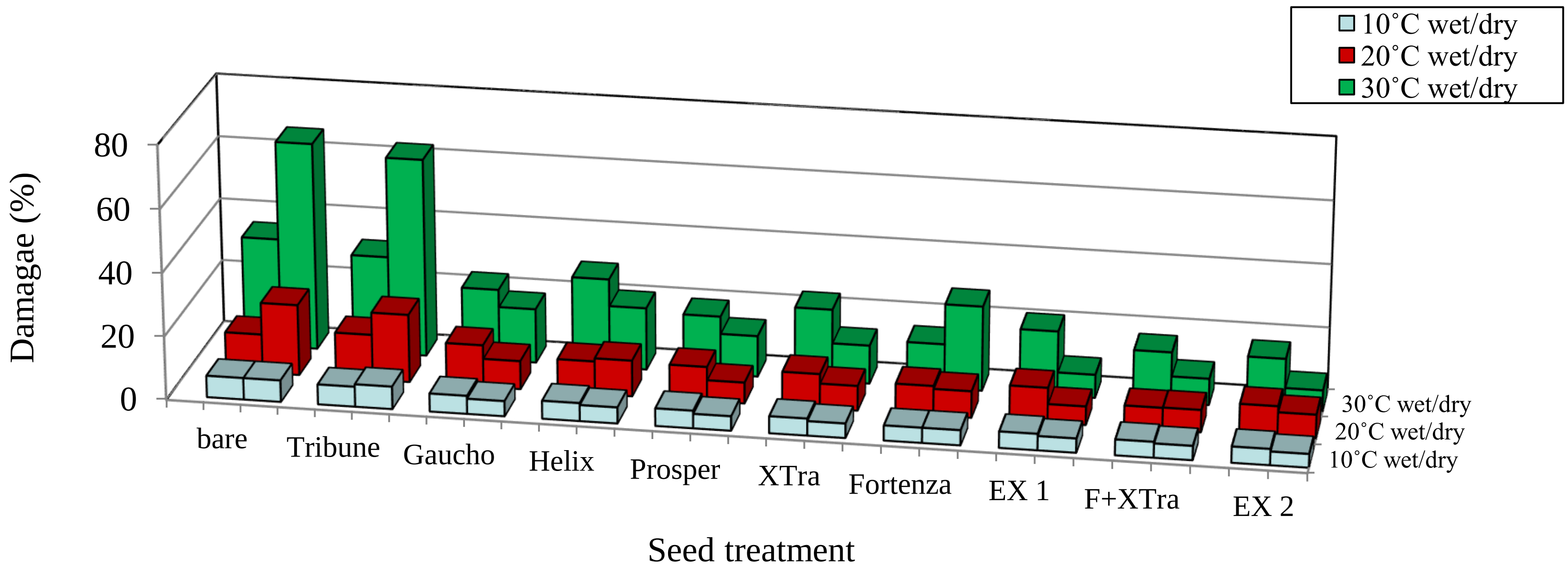
Fig. 17. Feeding damage to canola seedlings grown with different seed treatments and exposed to striped flea beetles for 24 h in wet and dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	4.3ab	4.4a	7.7a	8.1a	21.5a	28.8a
Tribune	4.5a	4.7a	7.3a	8.8a	20.8a	29.4a
Gaucho CS FL	3.3bc	2.9bc	5.6b	4.3bc	10.9cd	6.3c
Helix	3.3bc	3.6ab	5.6b	5.4b	16.2b	8.6bc
Prosper FX	3.2bc	2.7bc	5.4bc	4.4bc	9.4de	6.5c
Helix XTra	3.3bc	2.6bc	5.3bc	4.6bc	11.8c	6.4c
Fortenza (F)	3.3bc	3.1bc	4.4c	5.0bc	6.2g	12.9b
EX 1	3.2bc	2.3c	5.5bc	4.1c	8.6ef	4.8c
F + XTra mix	2.9c	2.8bc	4.8bc	5.4b	6.9fg	4.9c
EX 2	3.4bc	2.4c	4.8bc	3.8c	7.6e-g	4.6c

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

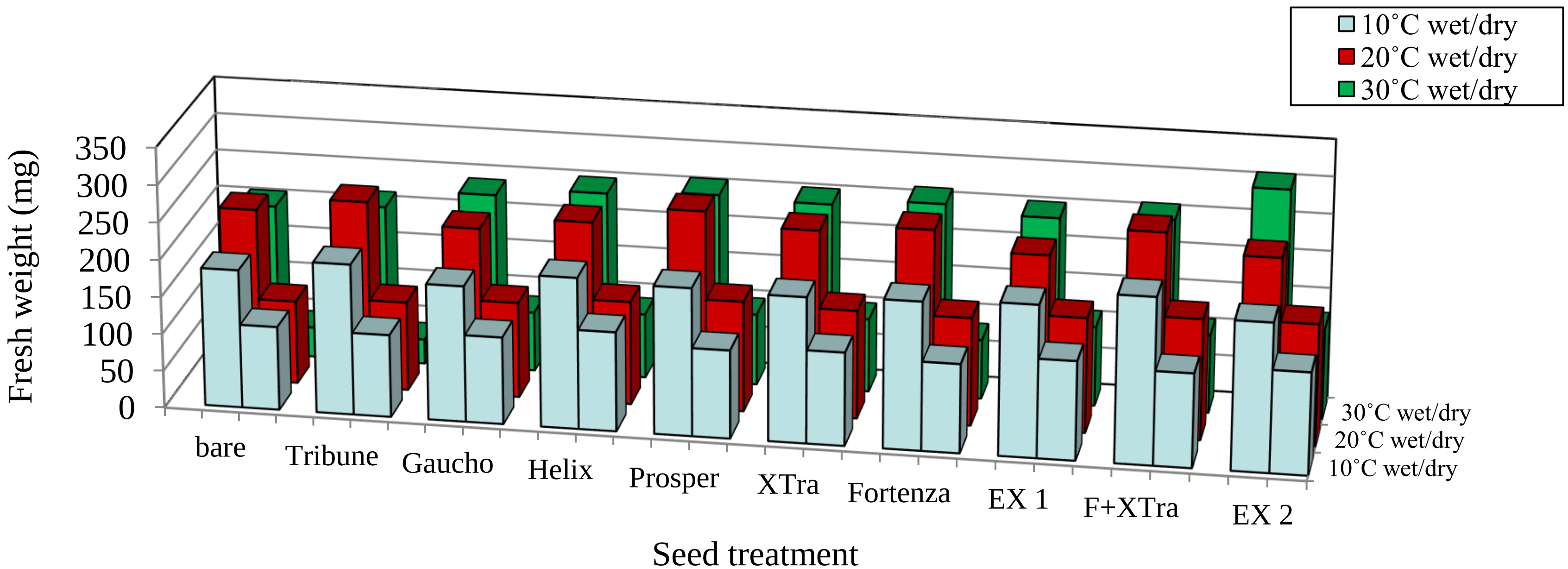
Fig. 18. Feeding damage to canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet and dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C wet	10°C dry	20°C wet	20°C dry	30°C wet	30°C dry
bare	6.8a	6.8a	12.2a-c	22.3a	34.5a	65.6a
Tribune	6.3ab	7.1a	14.3a	21.4a	30.9a	62.6a
Gaucho CS FL	5.7ab	4.8bc	13.2ab	8.9bc	22.6bc	17.1b-d
Helix	5.7ab	5.1b	10.3a-d	11.3b	28.1ab	19.6bc
Prosper FX	5.6ab	4.6bc	10.8a-c	6.6c	18.4c-e	12.9b-d
Helix XTra	5.4ab	4.6bc	10.8a-d	7.8bc	22.8bc	12.1cd
Fortenza (F)	4.8b	4.8bc	9.3cd	8.4bc	14.0e	26.7b
EX 1	5.2b	4.5bc	11.0a-c	5.9c	20.3cd	7.3d
F + XTra mix	5.0b	4.5bc	7.0d	7.1c	15.9de	8.3cd
EX 2	5.1b	4.3c	9.8b-d	7.9bc	16.1de	6.9d

[1] Means (% surface damaged) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

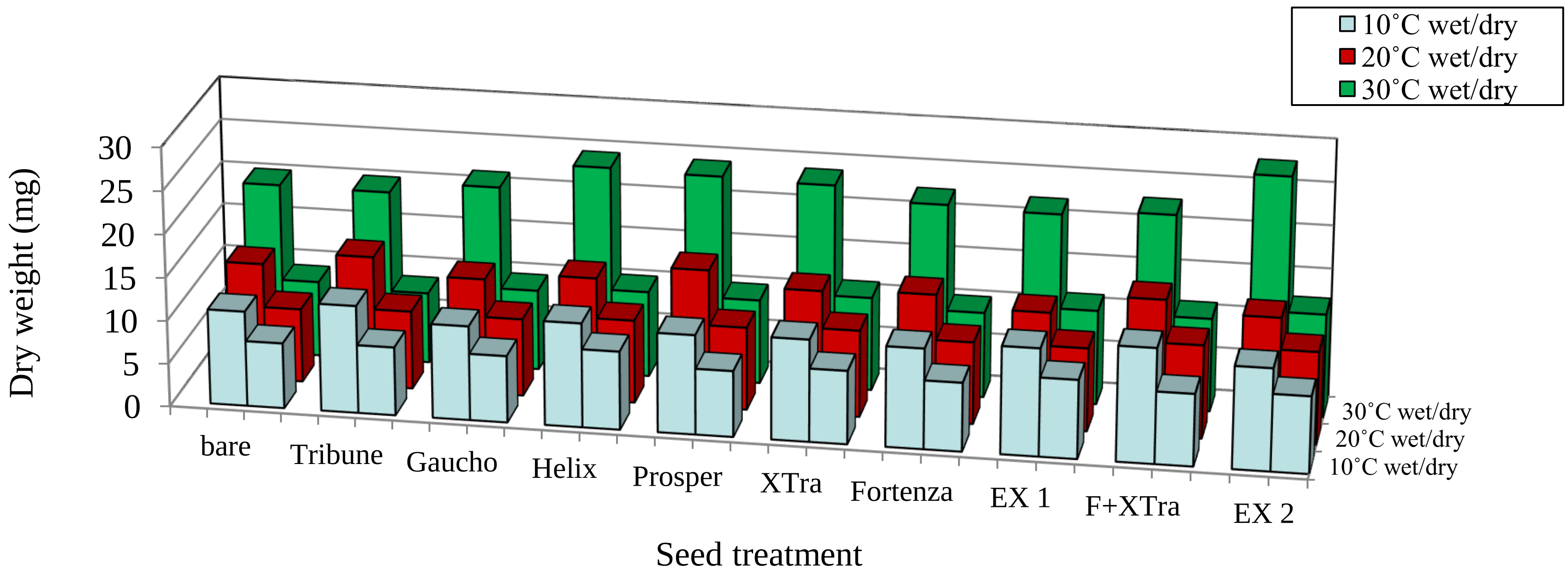
Fig. 19. Fresh weight of canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



Treatment	10°C		20°C		30°C	
	wet	dry	wet	dry	wet	dry
bare	185.6a	112.1a	232.8ab	111.4a	203.8a	40.0a
Tribune	202.4ab	110.6a	252.2ab	119.2a	211.6a	33.0a
Gaucho CS FL	182.5a	116.9ab	225.4a	128.1ab	237.0ab	79.4b
Helix	203.0ab	133.4bc	242.8ab	138.6bc	248.1b	86.3bc
Prosper FX	198.5ab	118.6ab	266.5ab	148.3c-e	254.9b	95.5b-d
Helix XTra	195.8ab	125.3a-c	249.8ab	145.4b-d	251.0b	98.4cd
Fortenza (F)	199.3ab	119.6ab	259.7ab	145.1b-d	260.4b	79.5b
EX 1	204.4ab	133.1bc	235.0ab	154.6c-e	250.3b	106.4de
F + XTra mix	224.1b	126.5a-c	274.5b	162.6de	257.0b	105.0d
EX 2	199.8ab	137.5c	249.8ab	165.1e	306.3c	122.7e

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Fig. 20. Dry weight of canola seedlings grown with different seed treatments and exposed to striped flea beetles for 72 h in wet soil or dry soil at 10, 20 and 30°C in 2012. [1]



	10°C		20°C		30°C	
Treatment	wet	dry	wet	dry	wet	dry
bare	11.0a	7.6a	13.5a	8.5a	19.9a	8.7ab
Tribune	12.4ab	7.9ab	15.1a	9.0a	19.8a	8.2a
Gaucho CS FL	10.9a	7.7a	13.3a	8.9a	21.1ab	9.3ab
Helix	12.0ab	9.1c	14.2a	9.6ab	24.2c	9.9bc
Prosper FX	11.5ab	7.6a	15.9a	9.6ab	23.9bc	9.7bc
Helix XTra	11.9ab	8.5a-c	14.3a	10.0ab	23.6bc	10.8cd
Fortenza (F)	11.6ab	7.9ab	14.7a	9.5ab	22.1a-c	9.9bc
EX 1	12.4ab	9.1c	13.4a	9.6ab	21.7a-c	10.9cd
F + XTra mix	13.3b	8.3a-c	15.7a	10.8b	22.5a-c	10.8cd
EX 2	11.8ab	8.9bc	14.5a	10.8b	27.7d	12.1d

[1] Means (mg/seedling) in each column followed by the same letter are not significantly different (Waller-Duncan; k = 100).

Table 7. Ranking of seed treatments in bioassays on striped flea beetles in wet and dry soil in 2012. [1]

Treatment	Control (% mortality)		Protection (damage 24/72h)		Shoot weight (mg)		Overall	
	wet	dry	wet	dry	wet	dry	wet	dry
bare	8	10	9	9	9	9	9	10
Tribune	8	9	10	9	8	9	9	9
Gaucho CS FL	8	7	7	6	9	8	8	7
Helix	3	8	8	8	3	6	7	8
Prosper FX	3	4	5	3	3	4	5	4
Helix XTra	3	6	6	3	3	4	6	5
Fortenza (F)	1	5	1	7	3	7	2	6
EX 1	3	1	4	1	3	2	4	1
F + XTra mix	1	2	2	3	1	3	1	3
EX 2	3	3	3	1	1	1	3	2

[1] Rankings based on Waller-Duncan comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values.

Table 8. Spearman-rank correlations between flea beetle mortality with seed treatments in 2012 bioassays and associated feeding damage and plant weights at different moisture regimes and temperatures. [1]

		wet soil			dry soil		
Species	Variable	10°C	20°C	30°C	10°C	20°C	30°C
crucifer	damage - 24h	-0.56***	-0.66***	-0.75***	-0.61***	-0.64***	-0.75***
	- 48h	-0.66***	-0.70***	-0.72***	-0.71***	-0.79***	-0.80***
	- 72h	-0.59***	-0.82***	-0.78***	-0.70***	-0.81***	-0.82***
	fresh weight	0.22NS	0.49**	0.67***	0.42**	0.55***	0.62***
	dry matter	0.18NS	0.26NS	0.35*	0.27NS	0.43**	0.64***
striped	damage - 24h	0.03NS	-0.40**	-0.48**	-0.64***	-0.60***	-0.75***
	- 48h	-0.06NS	-0.41**	-0.50**	-0.67***	-0.63***	-0.77***
	- 72h	-0.12NS	-0.28NS	-0.53***	-0.49**	-0.62***	-0.77***
	fresh weight	0.13NS	0.23NS	0.29NS	0.25NS	0.61***	0.59***
	dry matter	0.09NS	0.19NS	0.19NS	0.21NS	0.59***	0.38*

[1] *, **, *** Spearman coefficient (n = 40 values) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 9. Air temperatures and rainfall at AAFC-Saskatoon in 2013.

Interval	Days after seeding canola mustard [1]	Air temperatures (°C)			Rainfall(mm)
		min.	max.	average	
May		-4.8	28.9	13.0	15.2
June		2.0	26.8	15.5	115.9
	0-7	5.1	23.4	14.3	6.1
	8-14	6.5	24.7	15.6	1.1
	15-21	2.0	24.6	14.5	1.5
	22-28	4.8	23.0	13.6	60.4

[1] Canola mustard seeded May 17, Roundup Ready canola and Clearfield canola seeded May 22 and May 23, respectively.

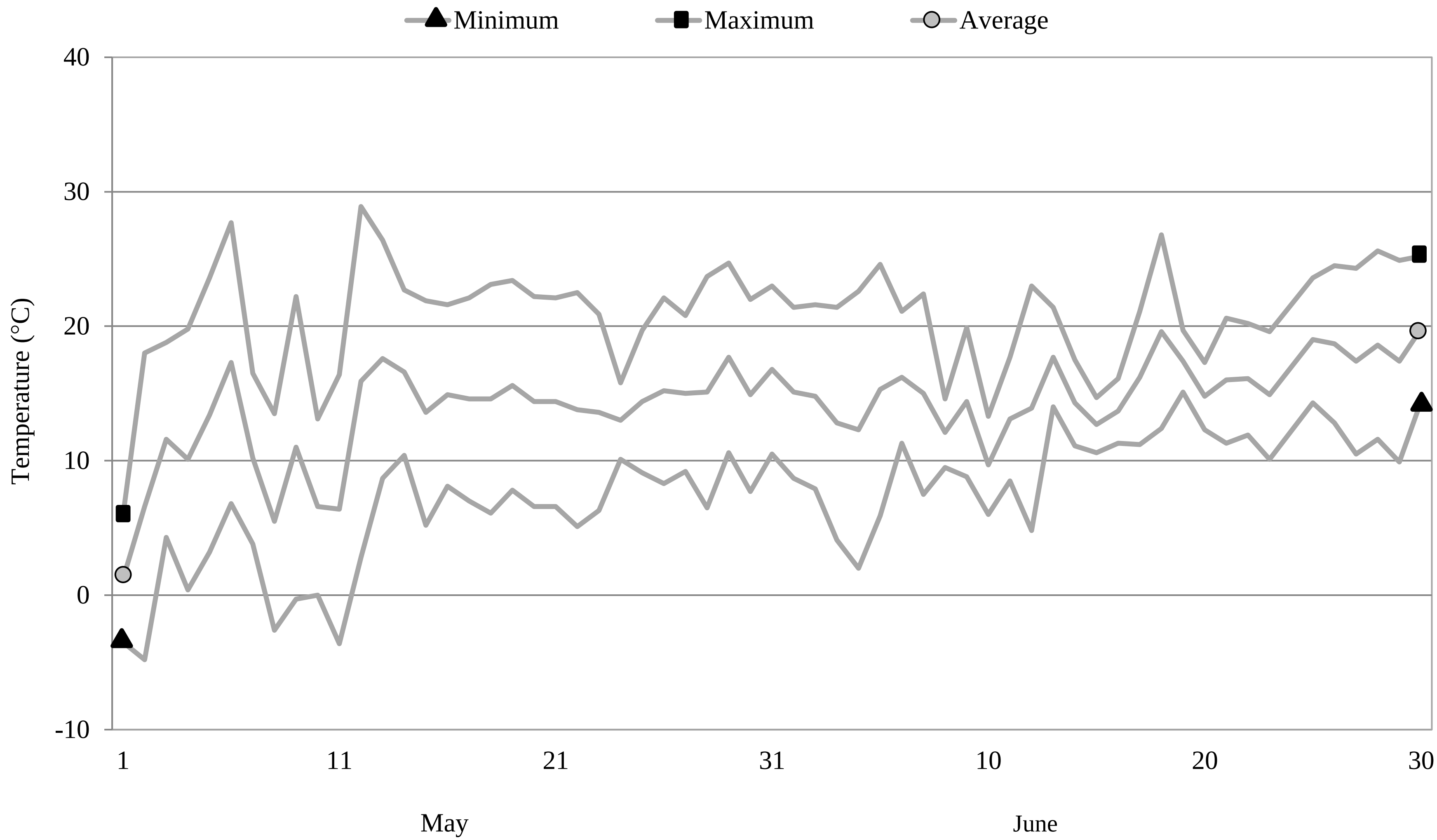


Fig. 21. Minimum, maximum and average daily air temperatures during May and June in 2013.

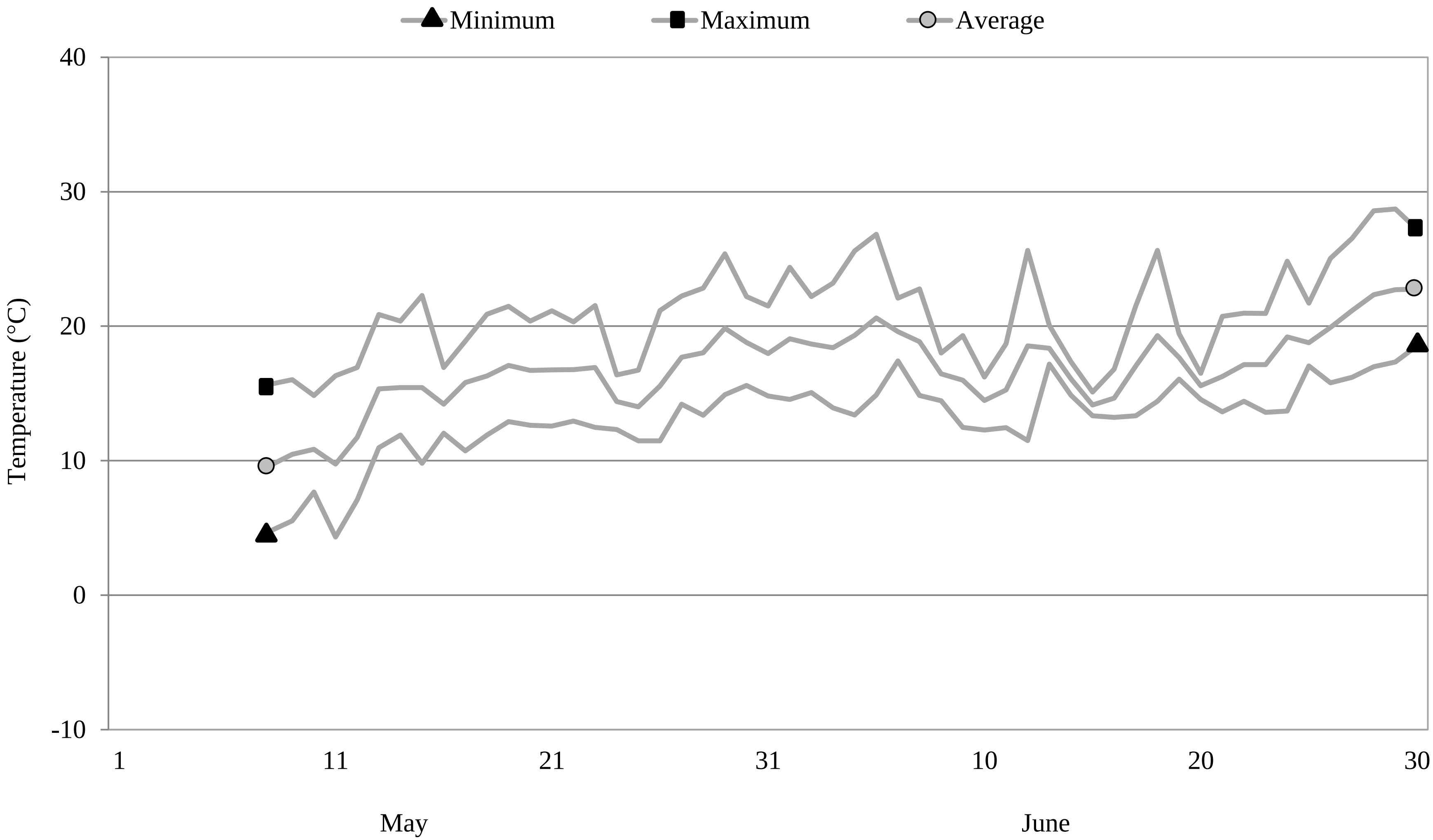


Fig. 22. Minimum, maximum and average daily soil temperatures (5 cm depth) during May and June in 2013.

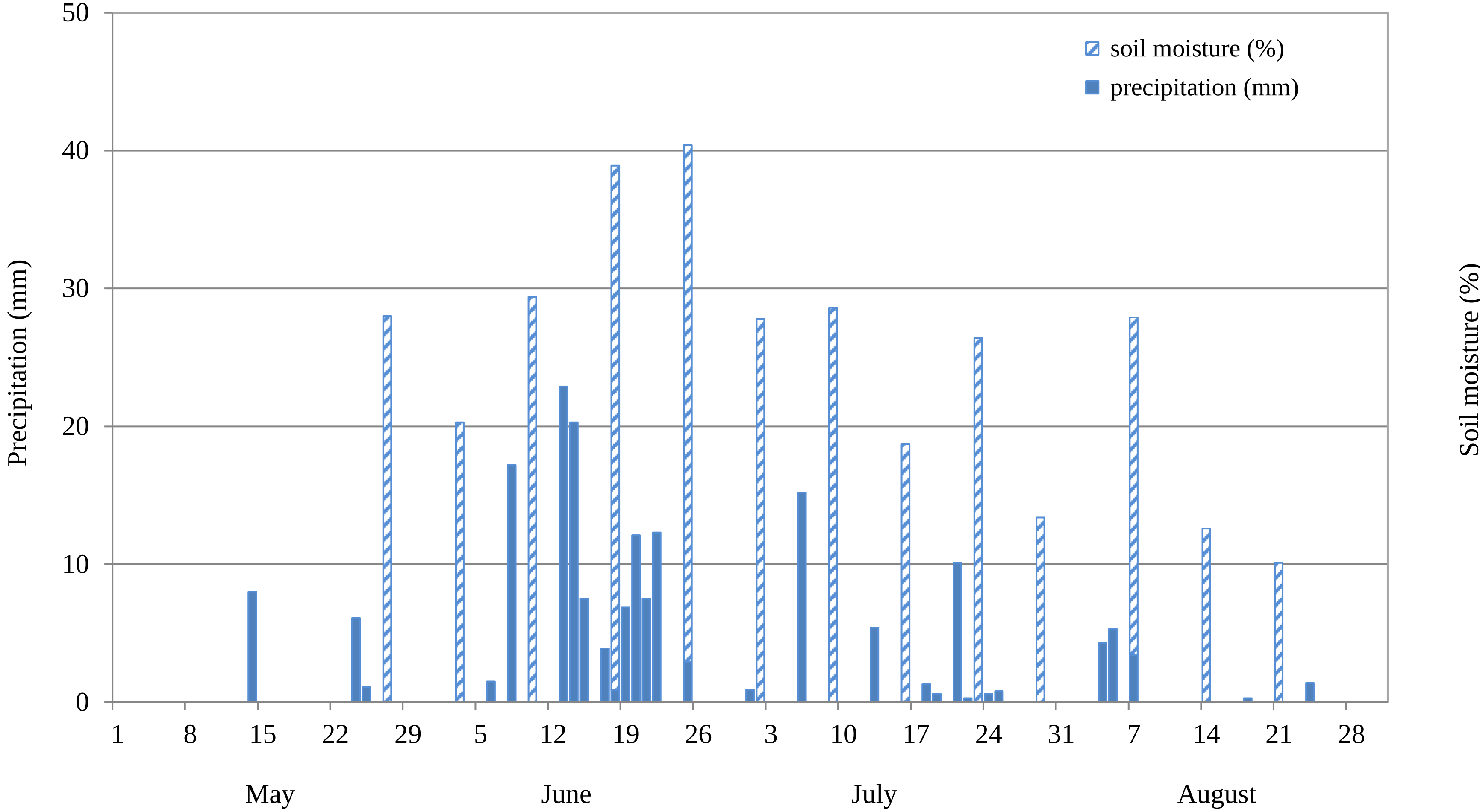


Fig. 23. Daily precipitation (solid bars) and soil moisture (hatched bars) at Saskatoon in 2013.

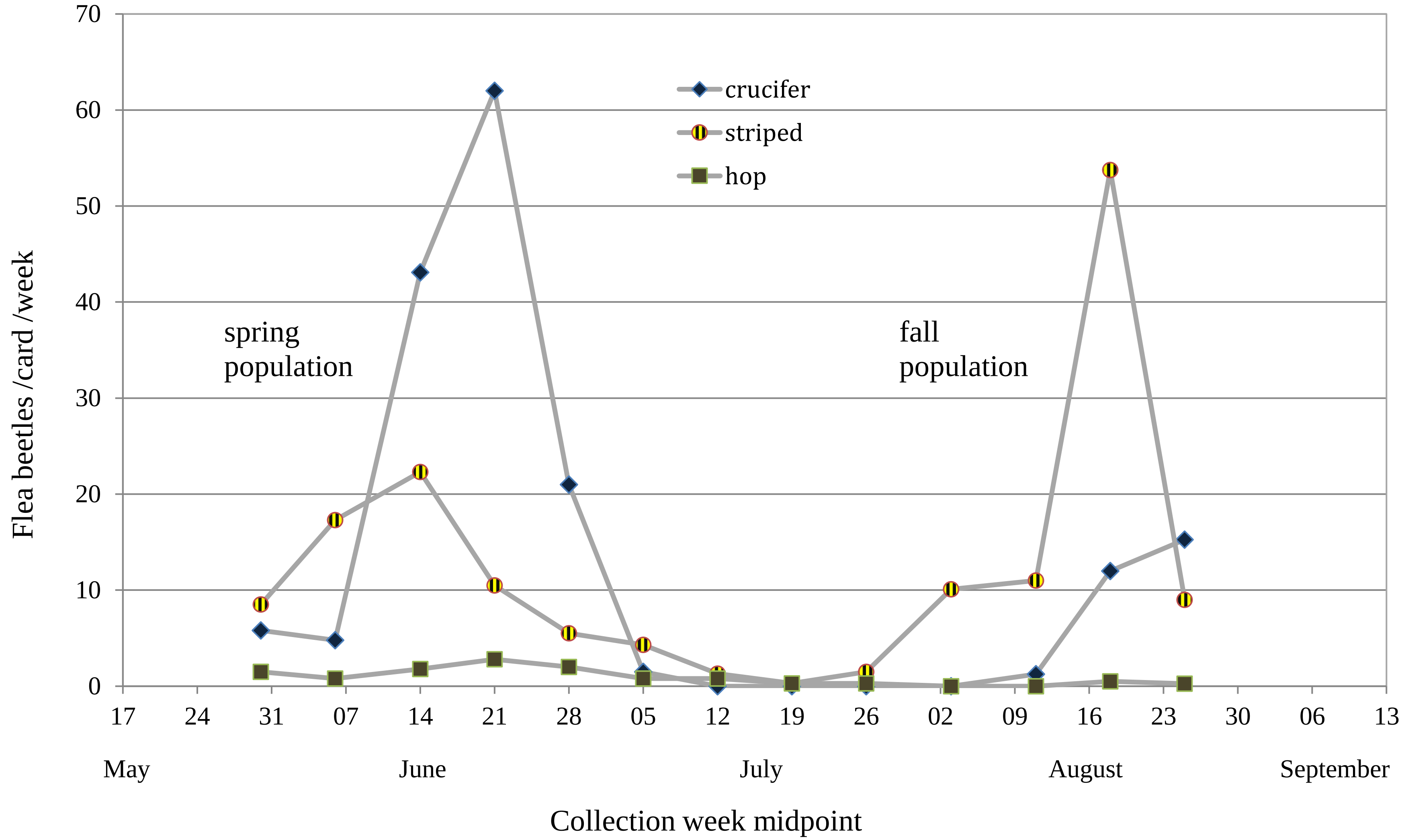


Fig. 24. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated Roundup Ready canola in 2013.

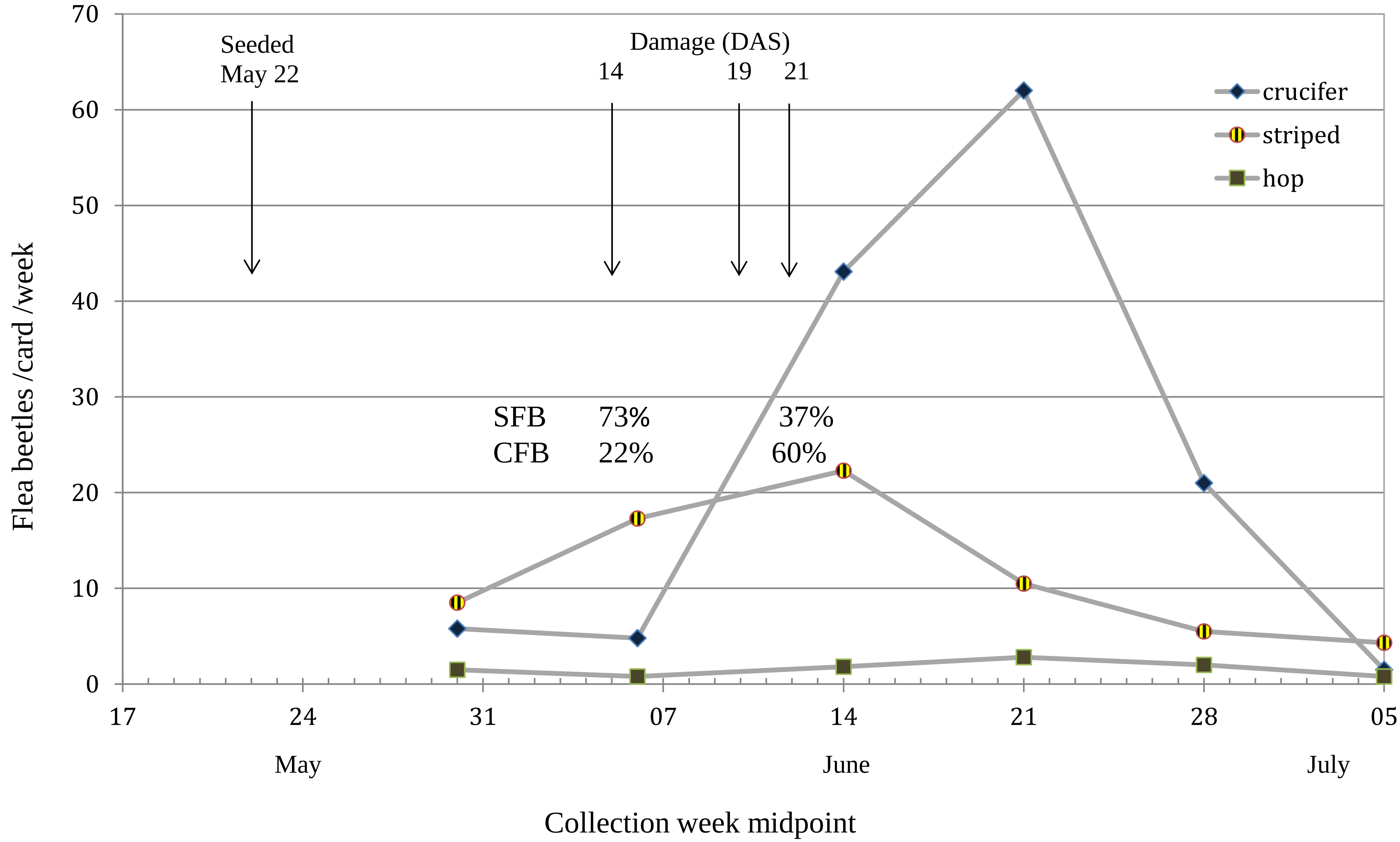


Fig. 25. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of Roundup Ready canola in 2013.

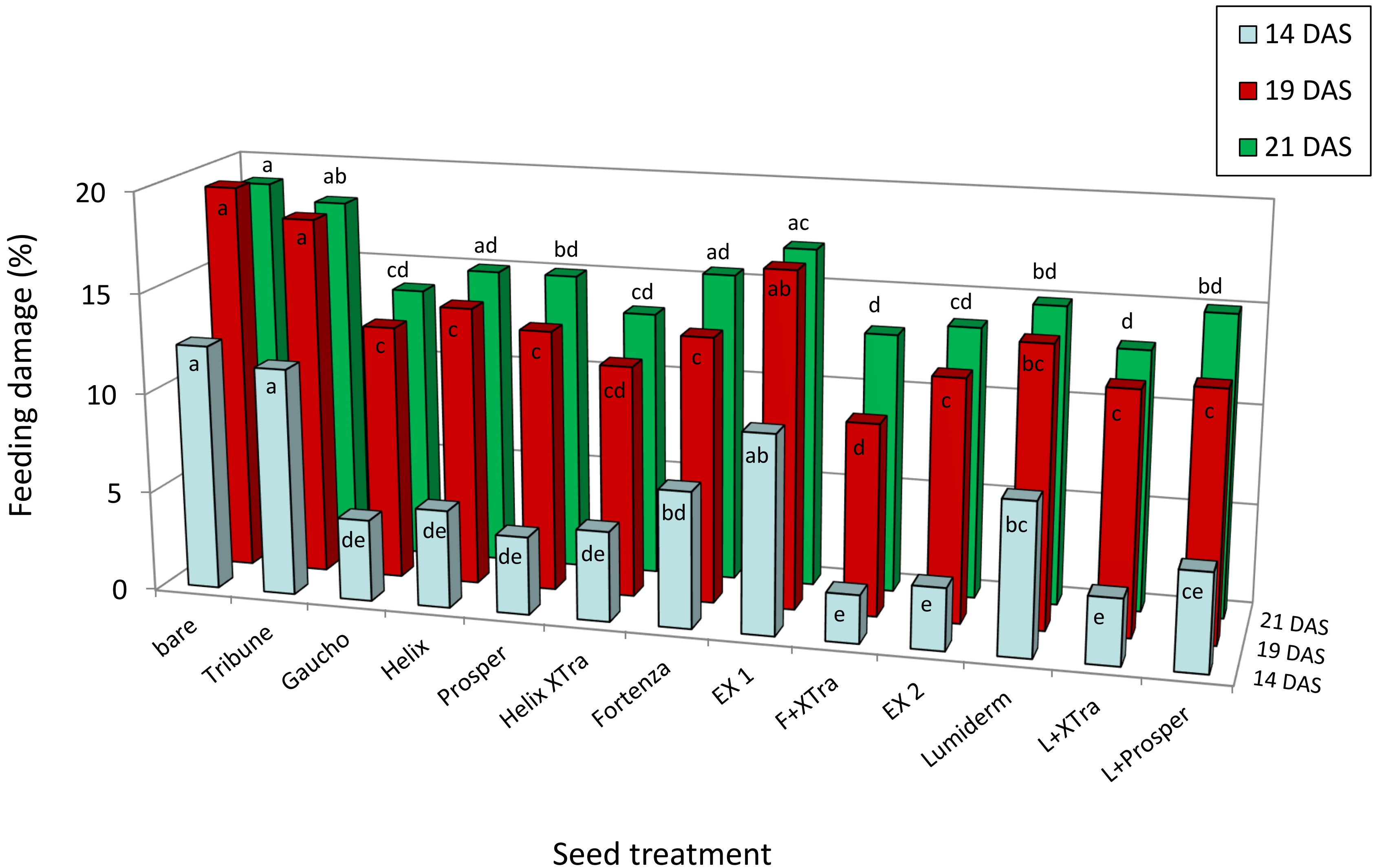


Fig. 26. Effect of seed treatments on flea beetle damage to Roundup Ready canola after 14, 19 and 21 days in 2013. In this and subsequent figures, means on each sampling date followed by the same letter are not significantly different (Waller-Duncan test, k = 100).

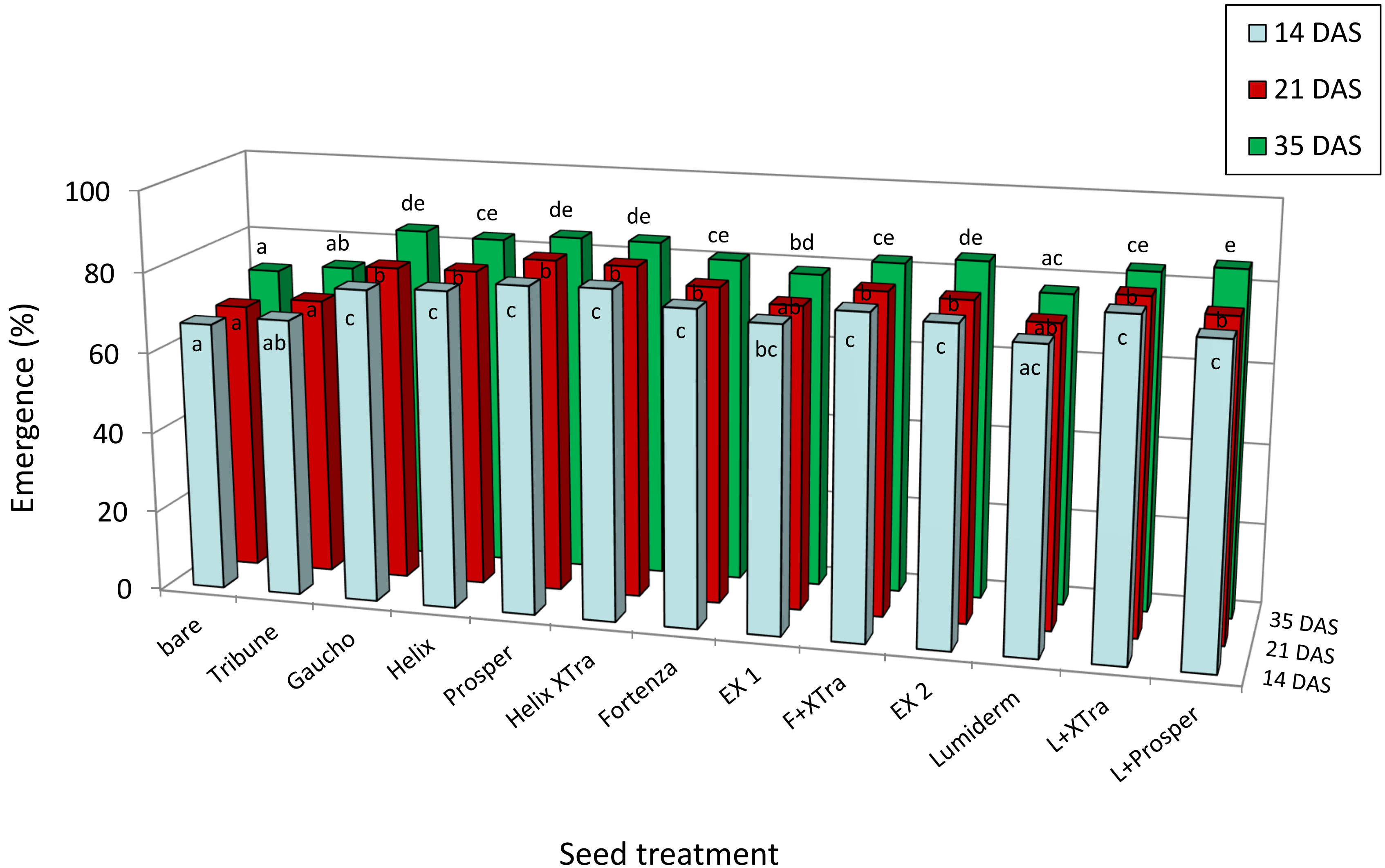


Fig. 27. Effect of seed treatments on emergence of Roundup Ready canola after 14, 21 and 35 days in 2013.

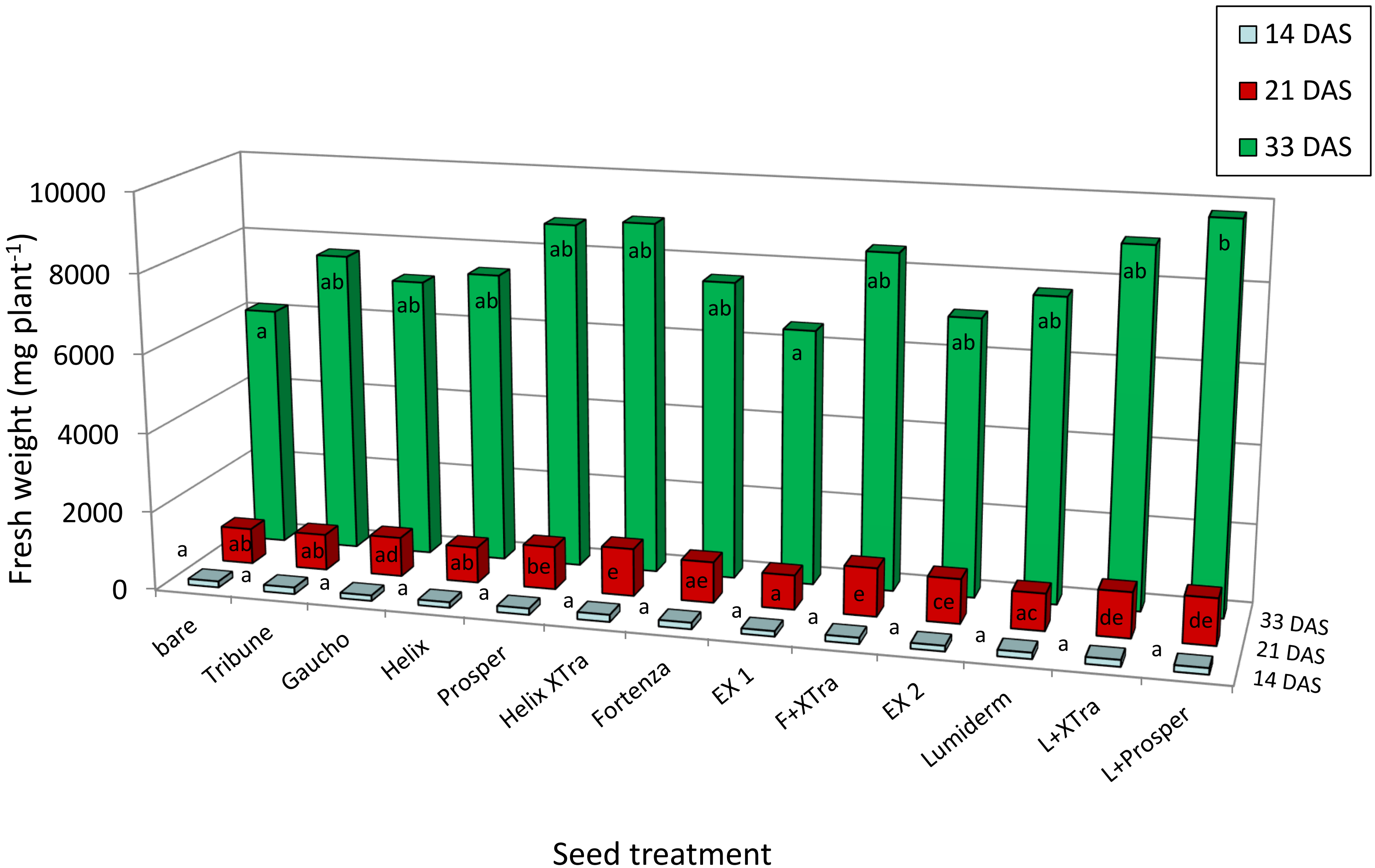


Fig. 28. Effect of seed treatments on fresh weight of Roundup Ready canola after 14, 21 and 35 days in 2013.

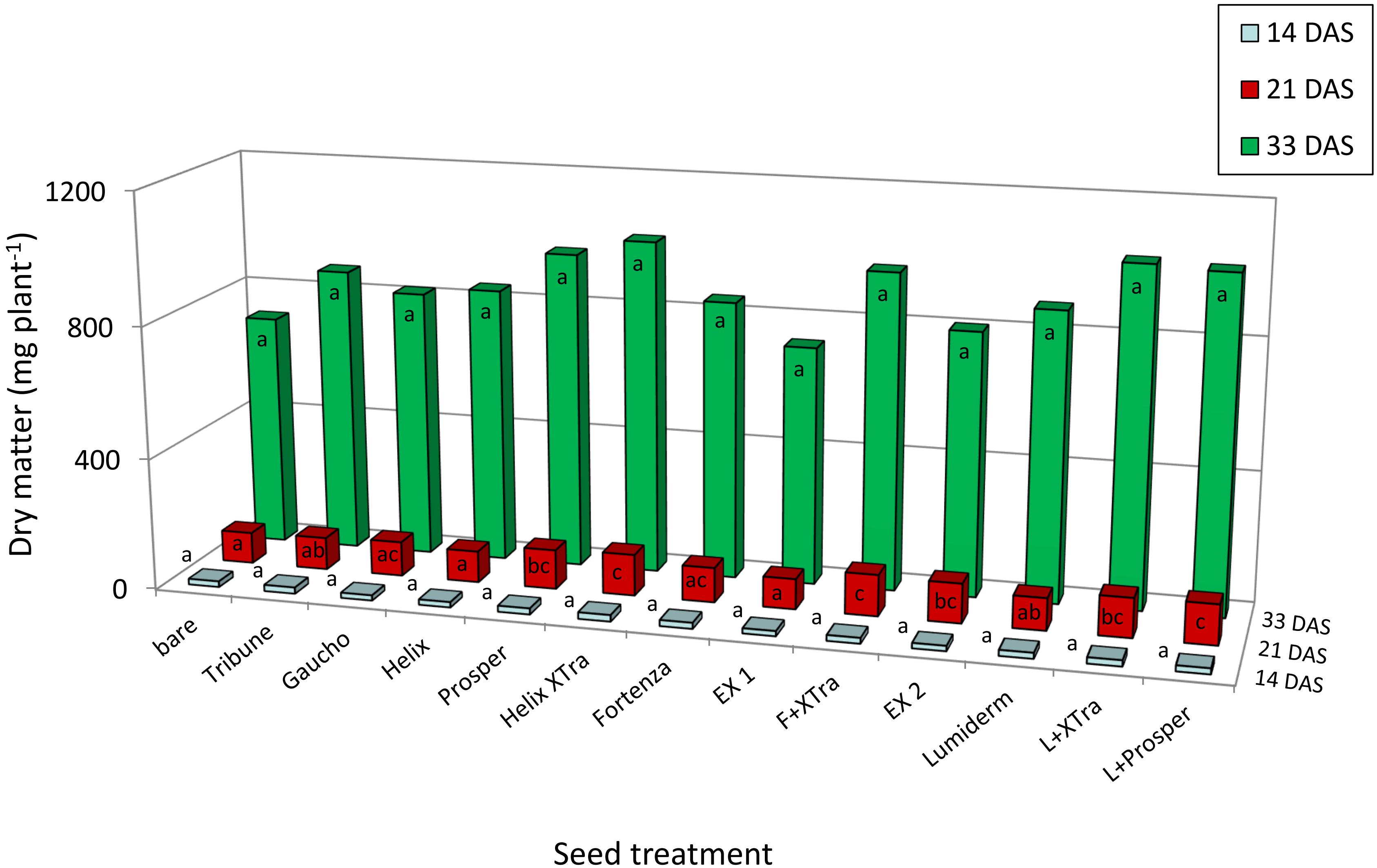


Fig. 29. Effect of seed treatments on dry matter content of Roundup Ready canola after 14, 21 and 33 days in 2013.

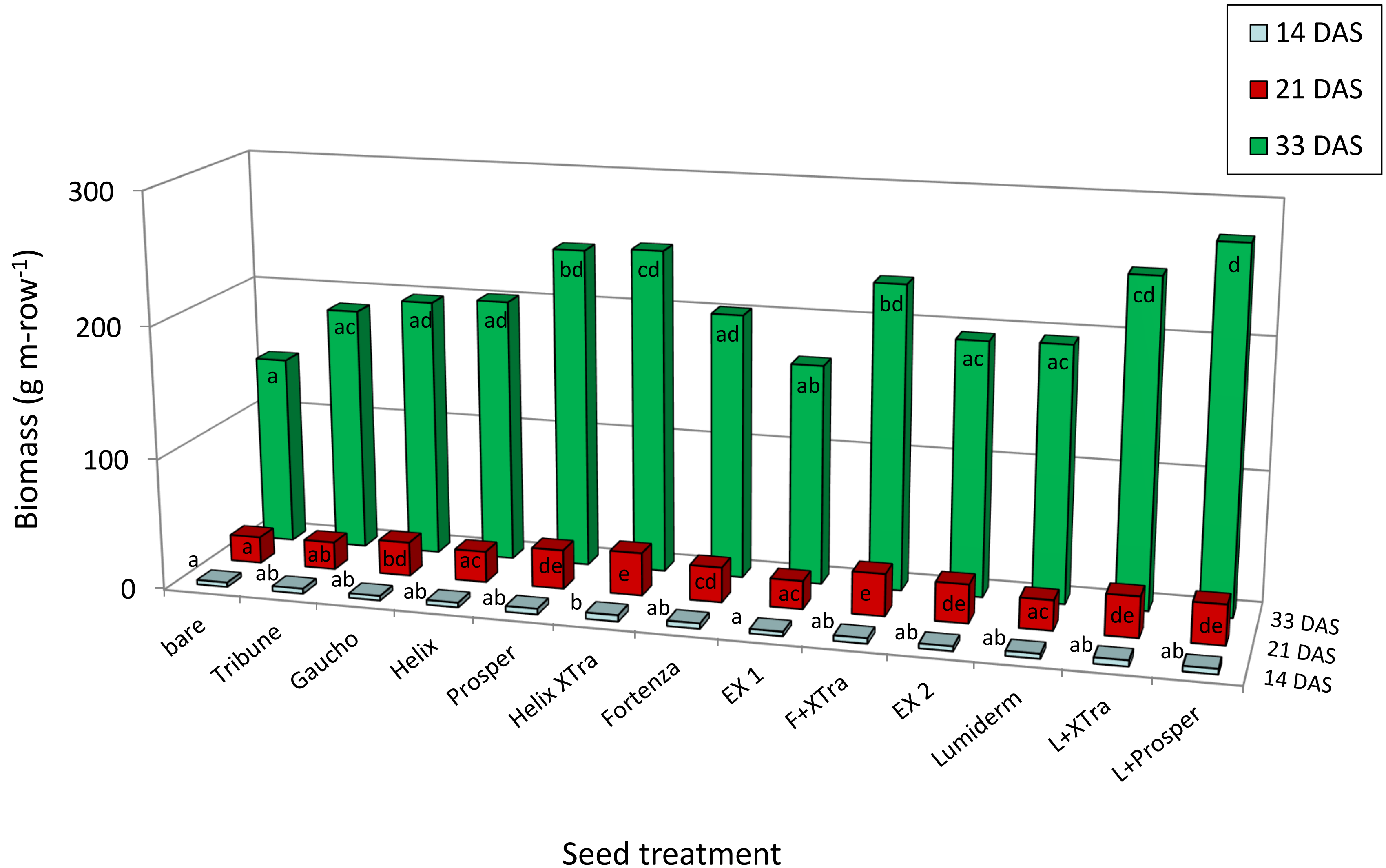


Fig. 30. Effect of seed treatments on biomass of Roundup Ready canola after 14, 21 and 33 days in 2013.

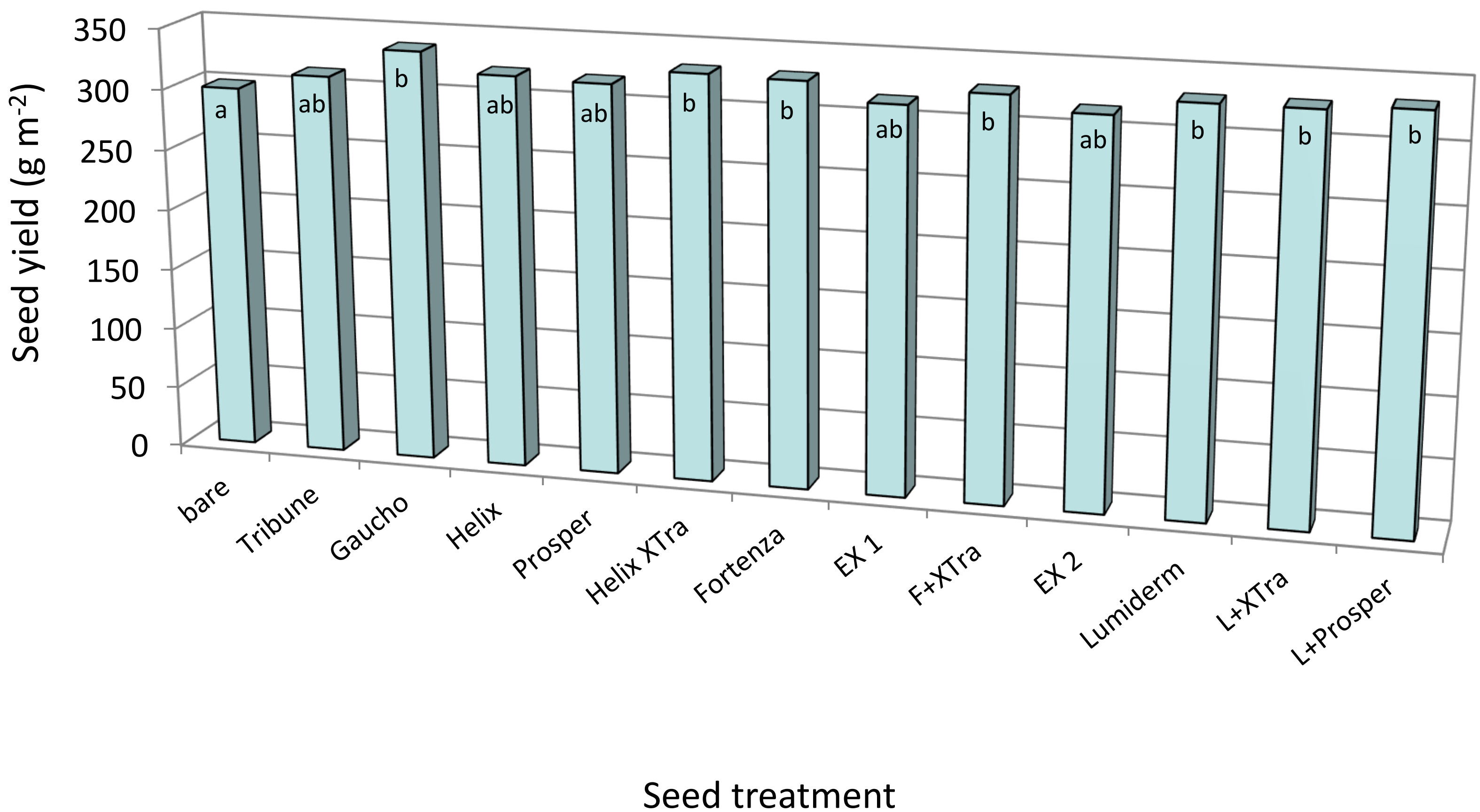


Fig. 31. Effect of seed treatments on seed yield of Roundup Ready canola in 2013.

Table 10. Ranking of seed treatments in field trial on Roundup Ready canola in 2013.

Treatment	Protection 14 DAS	Protection 21 DAS	Establishment 21 DAS	Biomass 33 DAS	Seed yield	Overall
bare	12	13	12	13	13	13
Tribune	12	12	12	9	12	12
Gaucho CS FL	4	3	1	6	1	5
Helix	4	8	1	6	8	9
Prosper	4	8	1	4	9	7
Helix XTra	4	3	1	2	3	3
Fortenza (F)	9	8	1	6	4	7
EX 1	11	11	10	12	11	11
F + XTra mix	1	1	1	4	7	2
EX 2	1	3	1	9	10	6
Lumiderm (L)	10	6	10	9	6	10
L + XTra mix	1	1	1	2	5	1
L + Prosper mix	4	6	1	1	2	4

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 22.

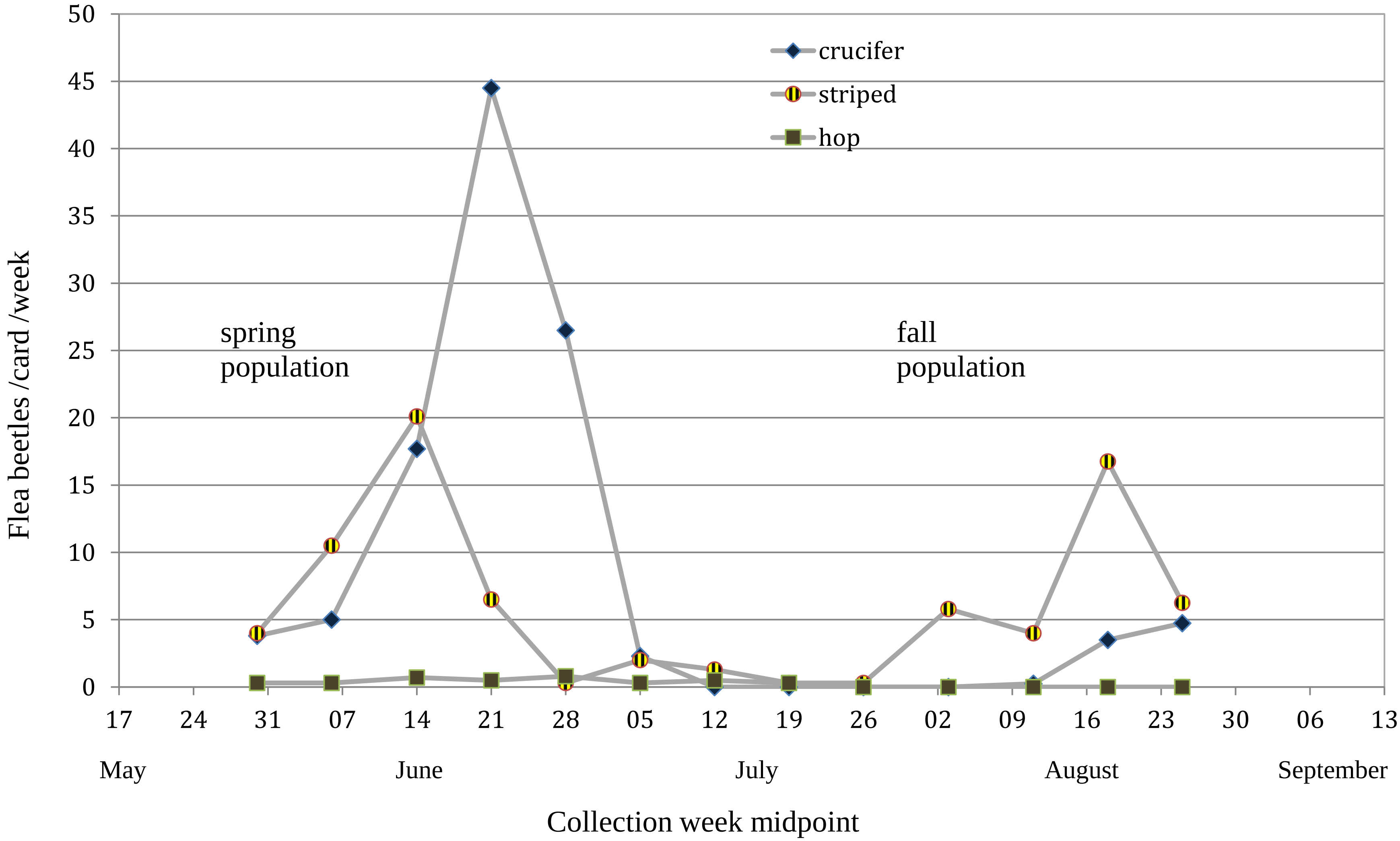


Fig. 32. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated Clearfield canola in 2013.

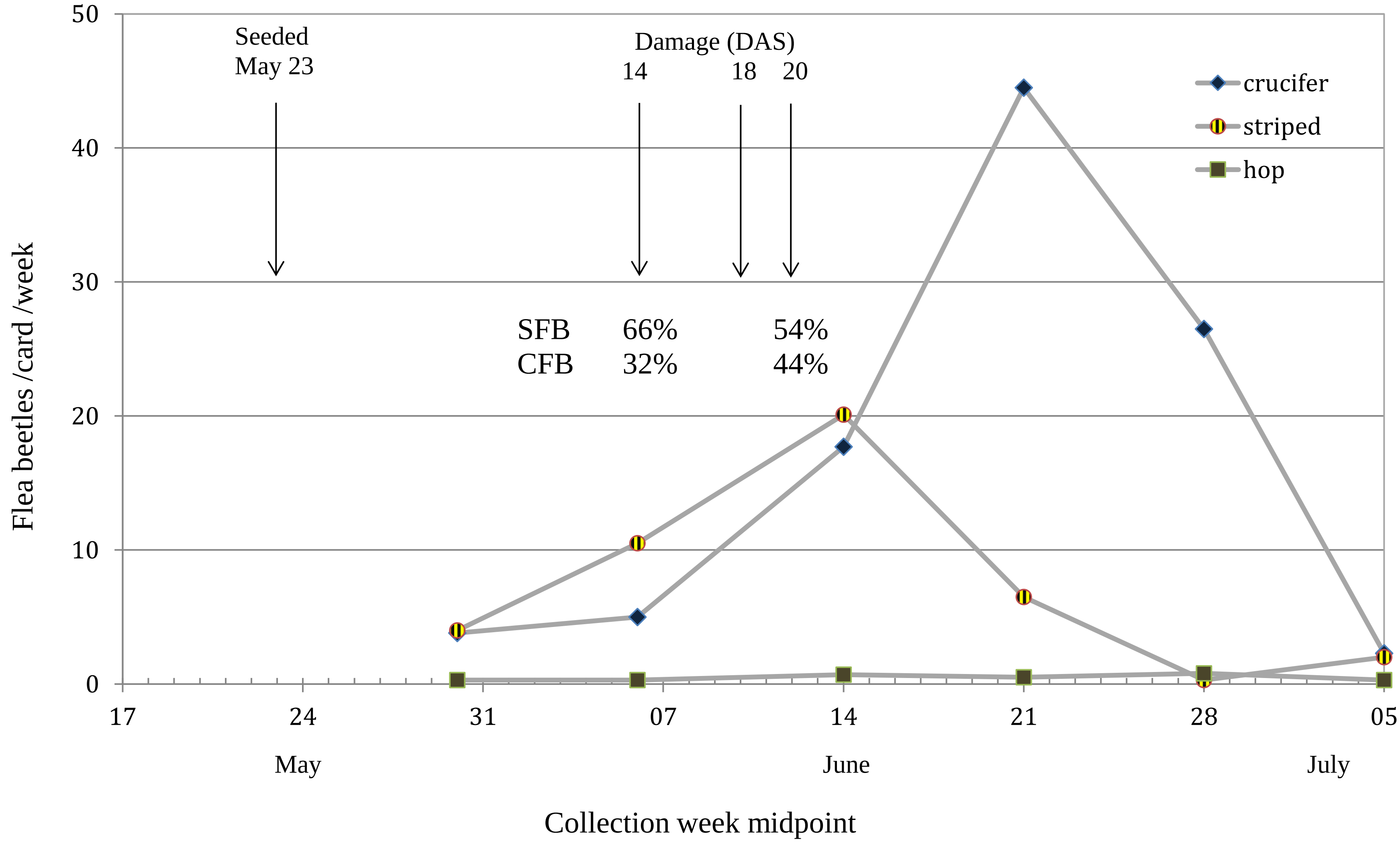


Fig. 33. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of Clearfield canola in 2013.

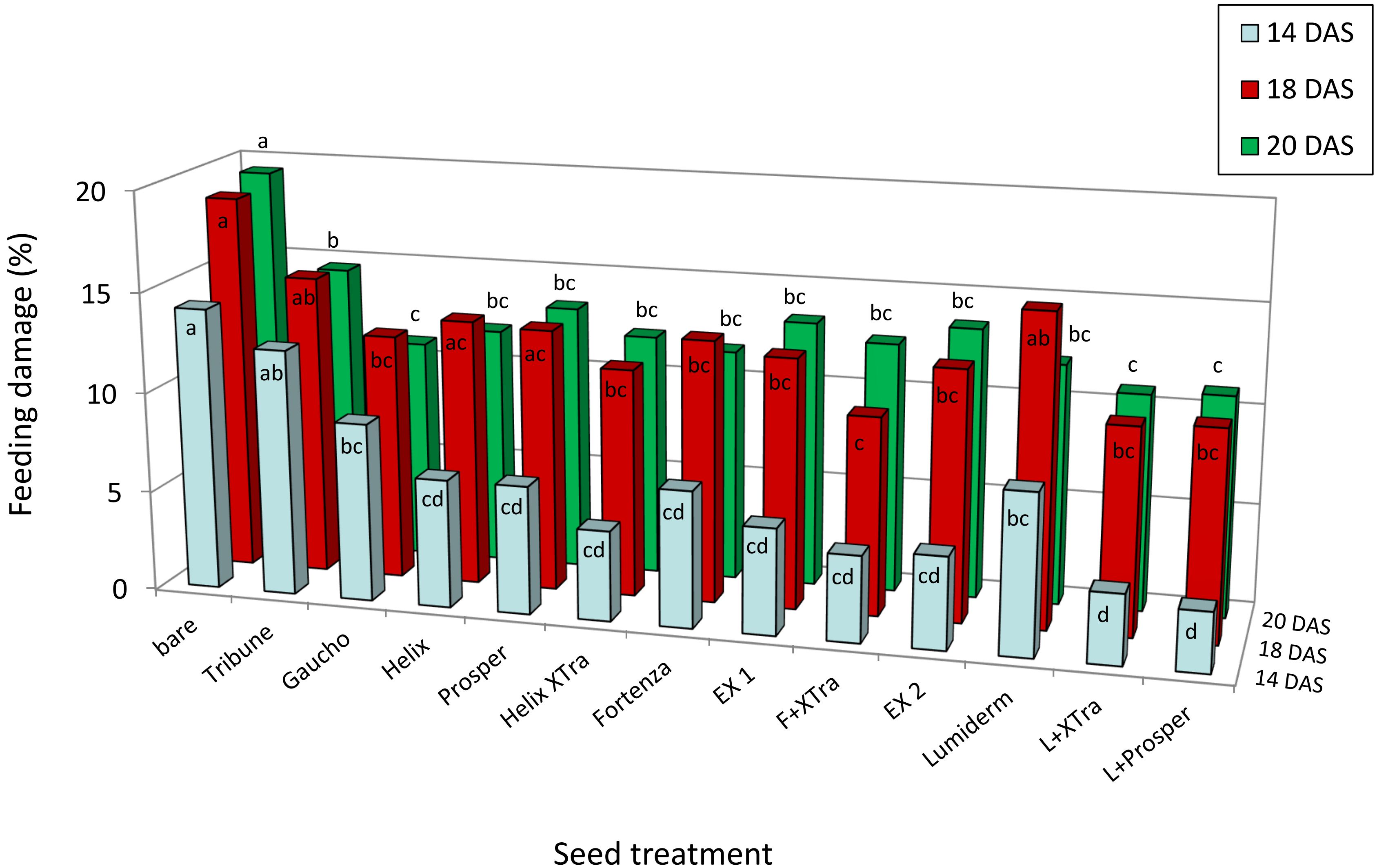


Fig. 34. Effect of seed treatments on flea beetle damage to Clearfield canola after 14, 18 and 20 days in 2013.

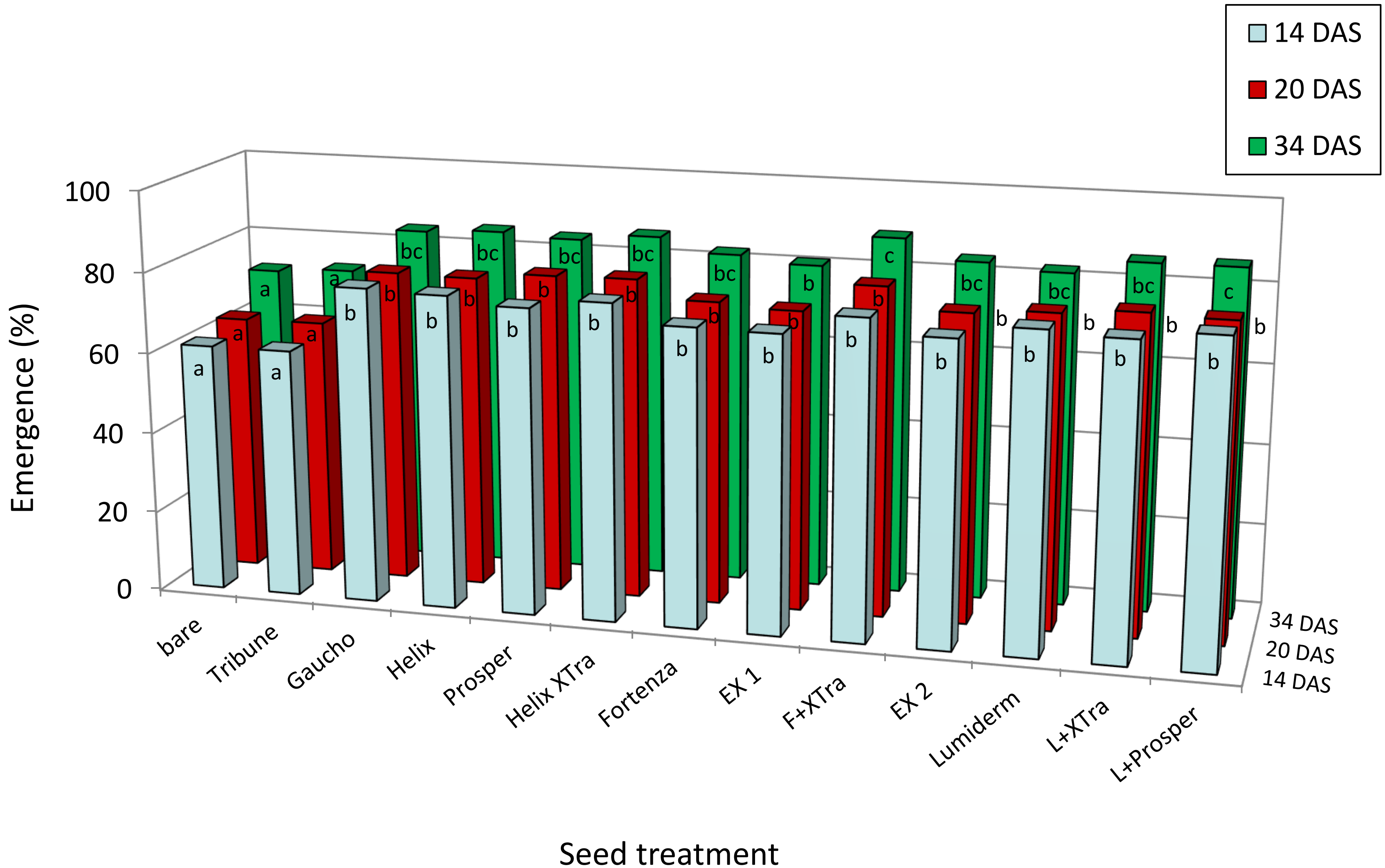


Fig. 35. Effect of seed treatments on emergence of Clearfield canola after 14, 20 and 34 days in 2013.

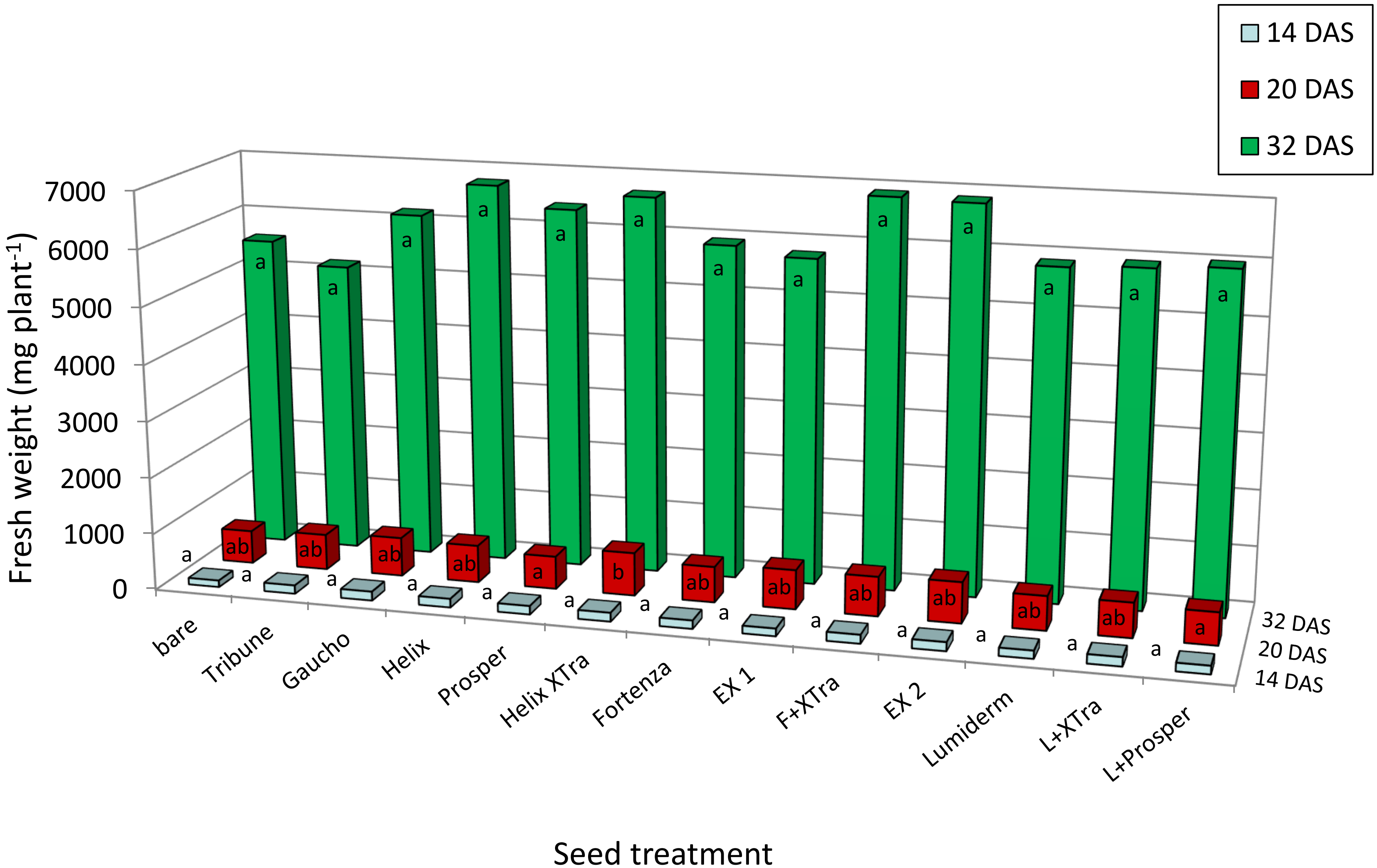


Fig. 36. Effect of seed treatments on fresh weight of Clearfield canola after 14, 20 and 32 days in 2013.

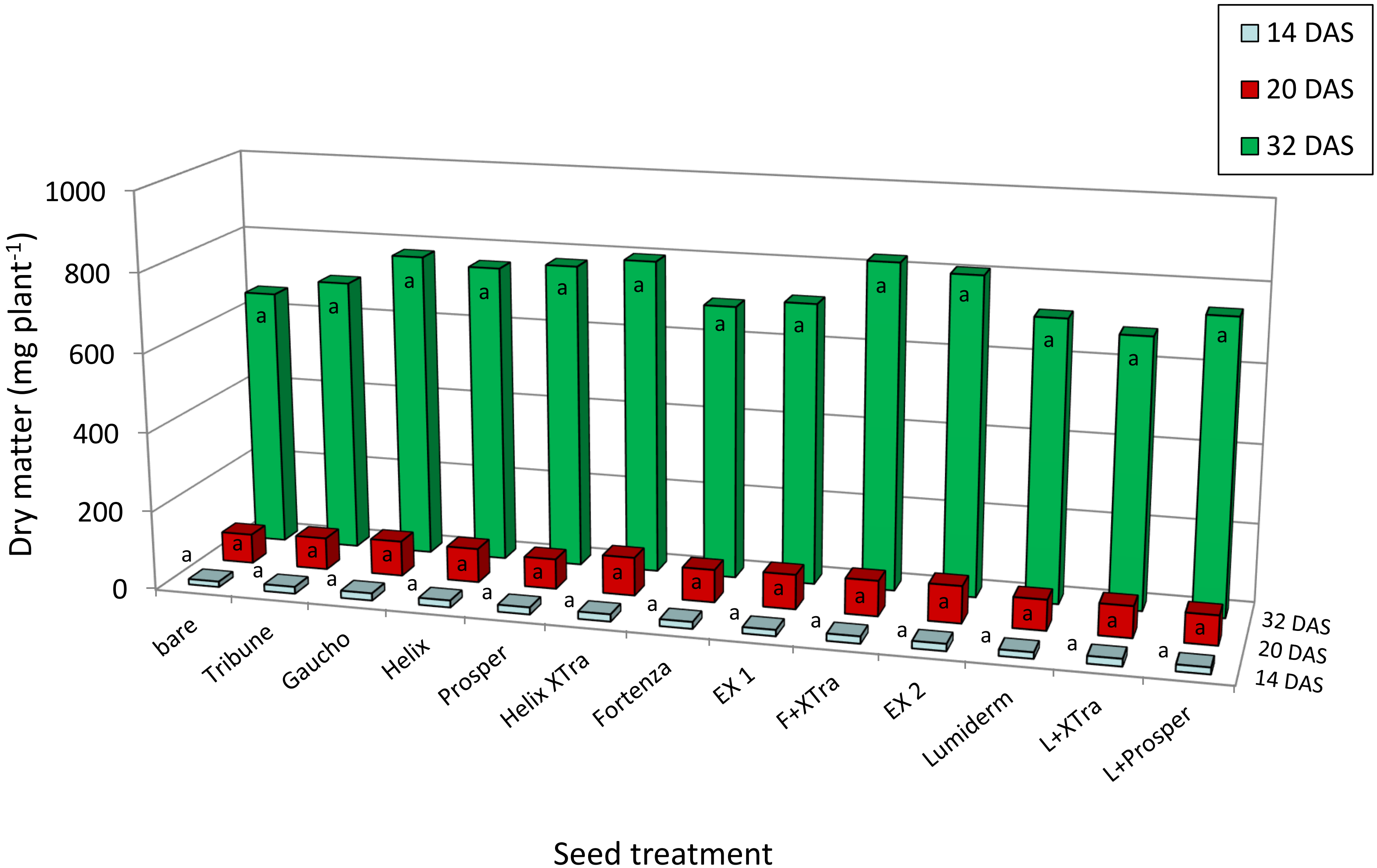


Fig. 37. Effect of seed treatments on dry matter content of Clearfield canola after 14, 20 and 32 days in 2013.

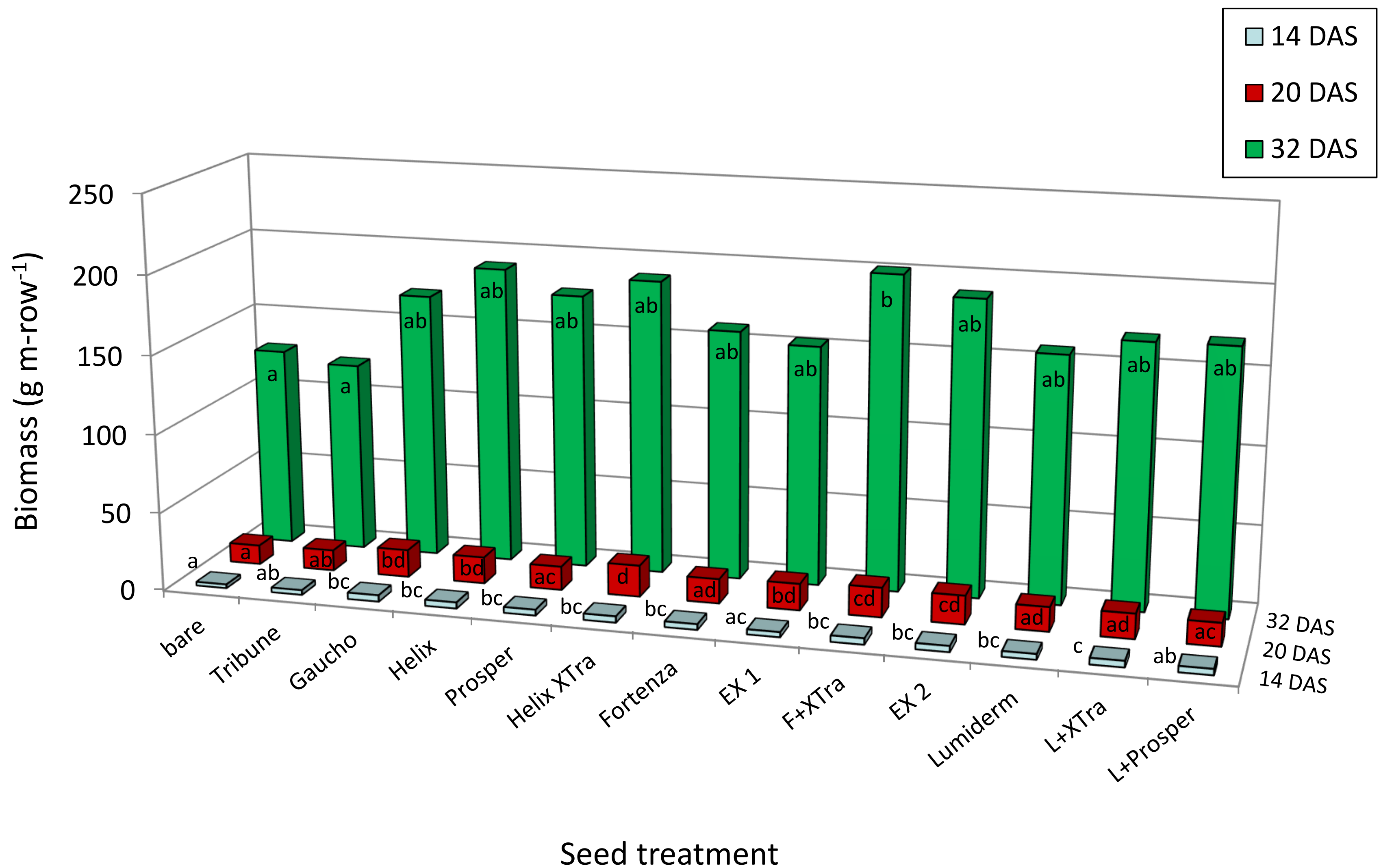


Fig. 38. Effect of seed treatments on biomass of Clearfield canola after 14, 20 and 32 days in 2013.

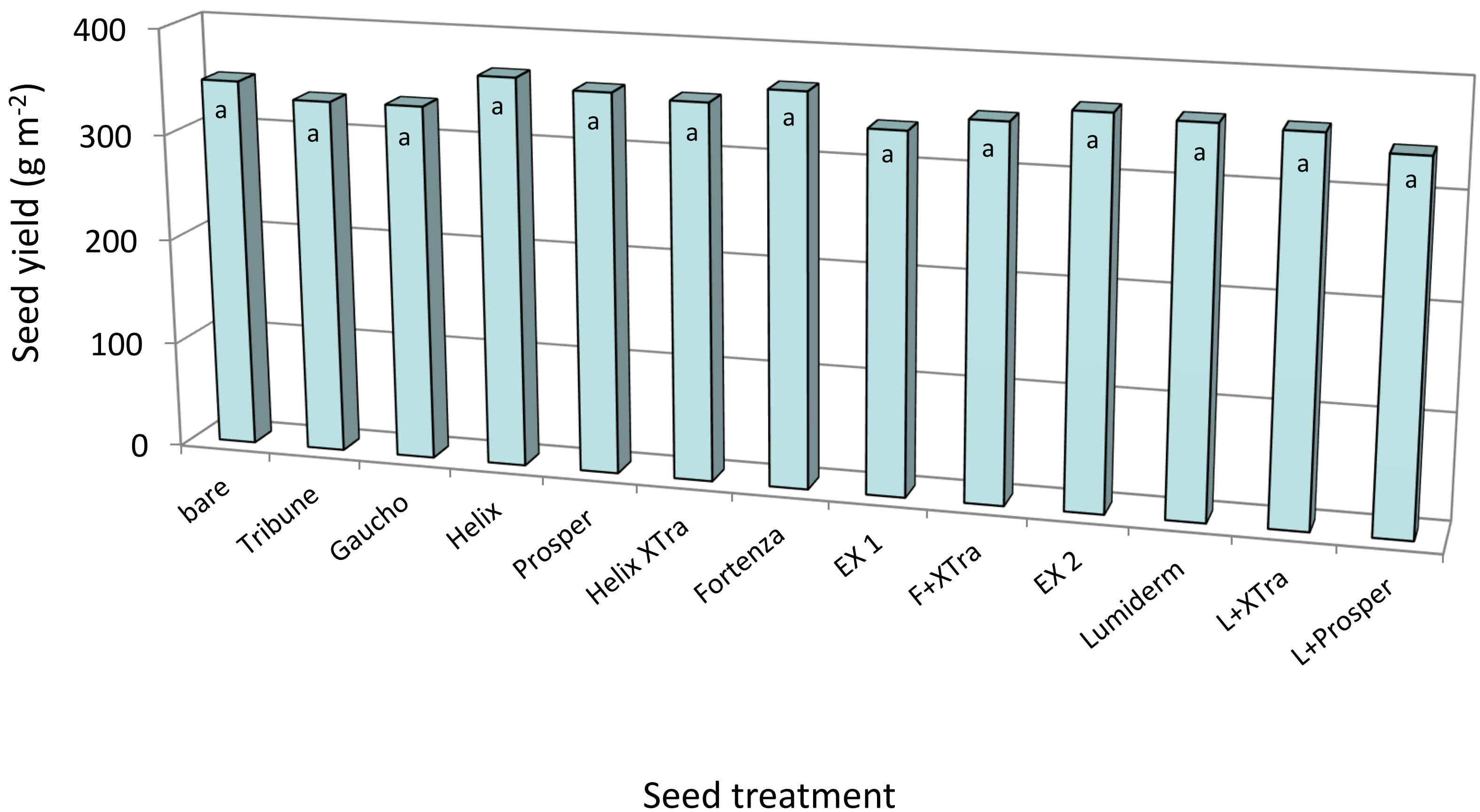


Fig. 39. Effect of seed treatments on seed yield of Clearfield canola in 2013.

Table 11. Ranking of seed treatments in field trial on Clearfield canola in 2013.

Treatment	Protection		Establishment	Biomass	Seed	
	14 DAS	21 DAS	21 DAS	28 DAS	yield	Overall
bare	13	13	12	1	1	13
Tribune	12	12	12	1	1	12
Gaucho CS FL	10	1	1	1	1	10
Helix	3	4	1	1	1	3
Prosper	3	4	1	1	1	3
Helix XTra	3	4	1	1	1	3
Fortenza (F)	3	4	1	1	1	3
EX 1	3	4	1	1	1	3
F + XTra mix	3	4	1	1	1	3
EX 2	3	4	1	1	1	3
Lumiderm (L)	10	4	1	1	1	11
L + XTra mix	1	1	1	1	1	1
L + Prosper mix	1	1	1	1	1	1

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 23.

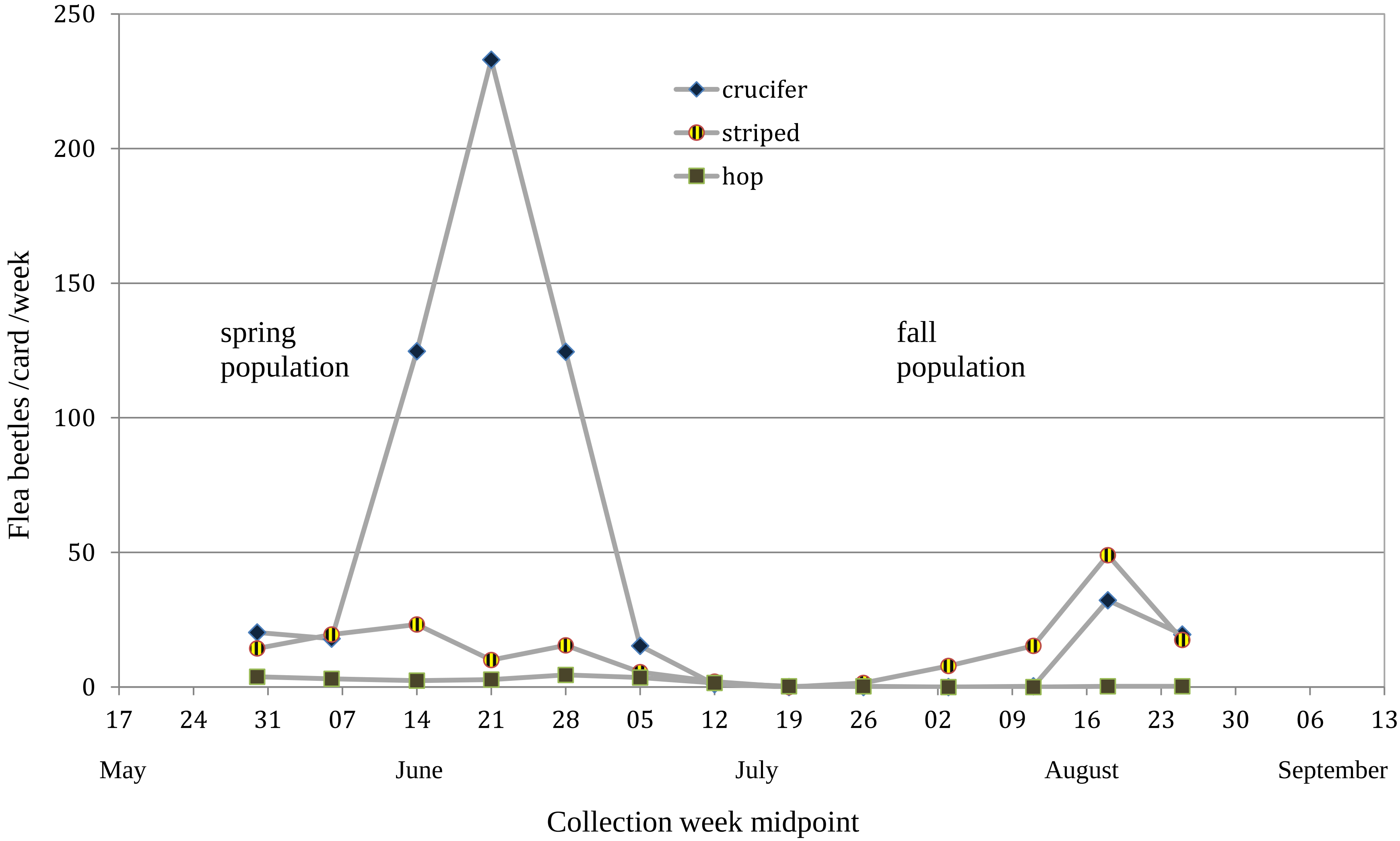


Fig. 40. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated canola mustard in 2013.

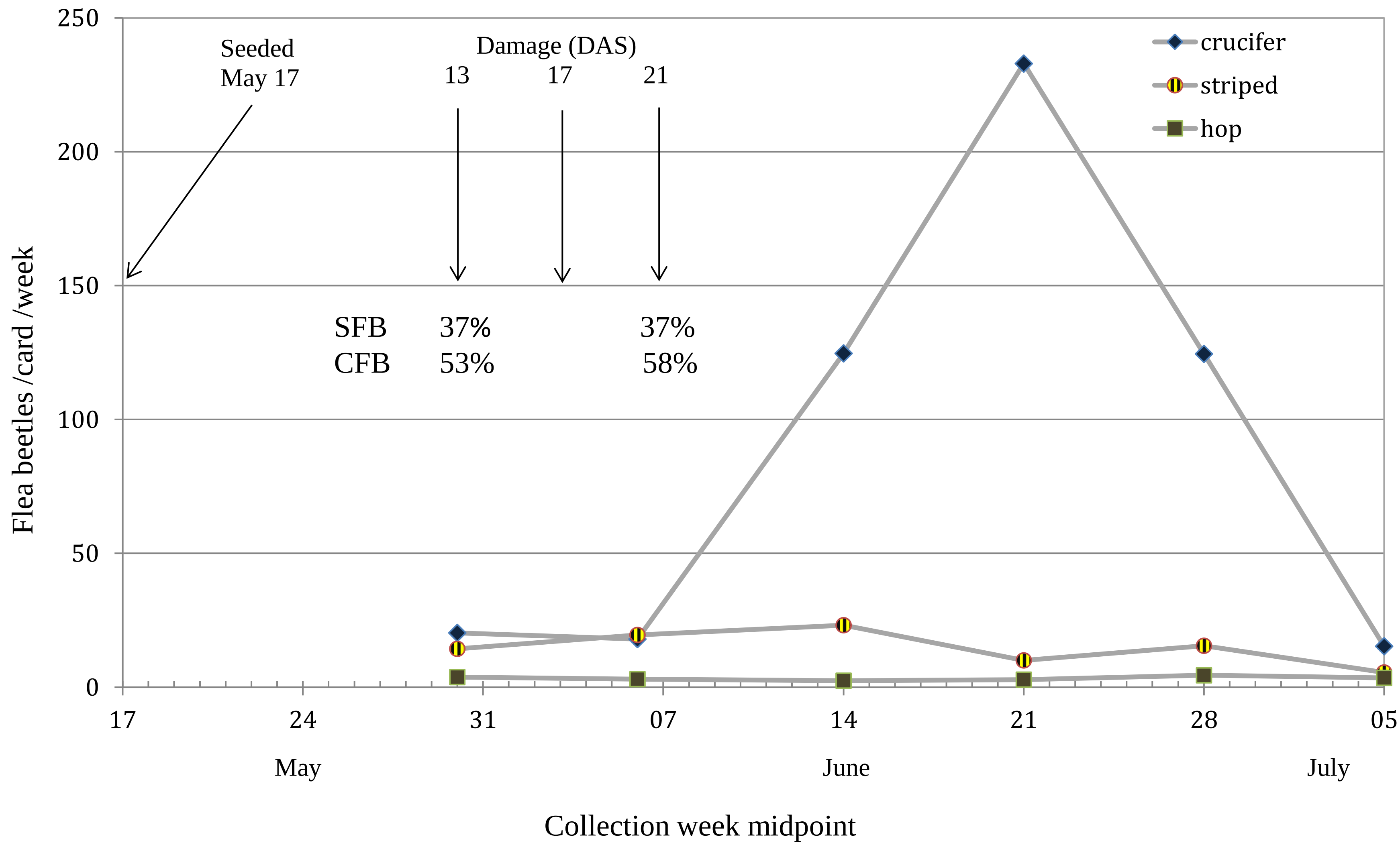


Fig. 41. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of canola mustard in 2013.

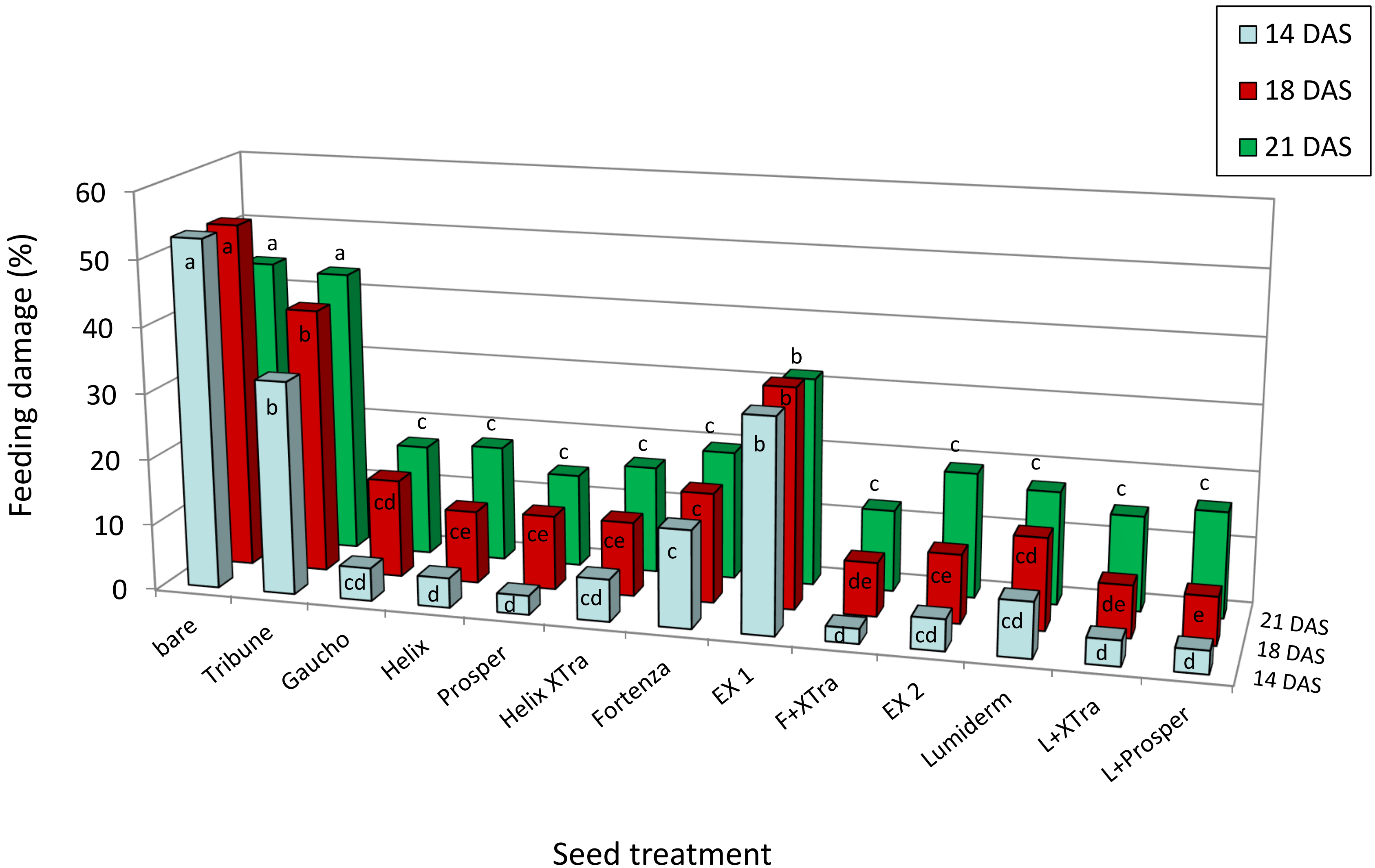


Fig. 42. Effect of seed treatments on flea beetle damage to canola mustard after 14, 18 and 21 days in 2013.

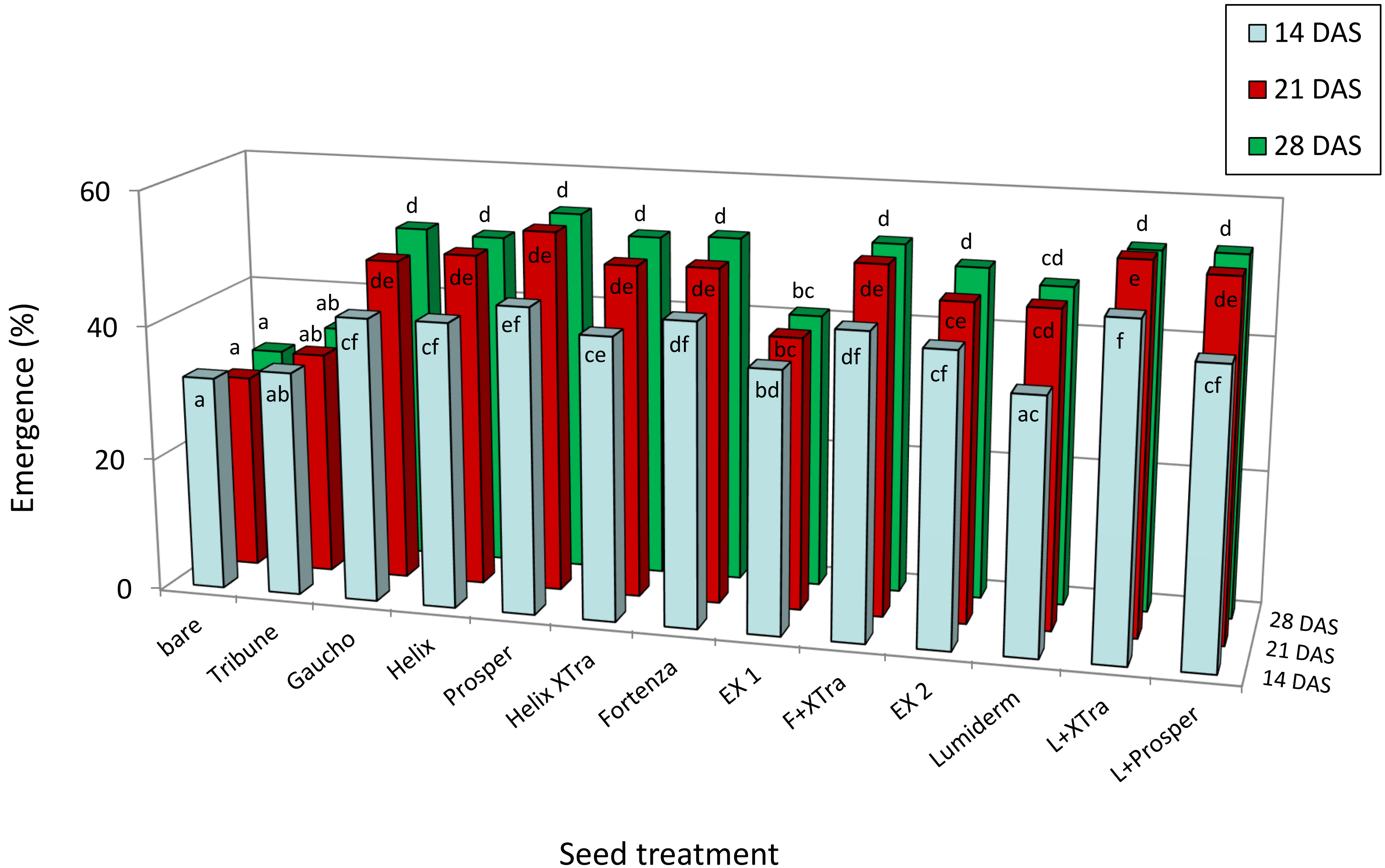


Fig. 43. Effect of seed treatments on emergence of canola mustard after 14, 21 and 28 days in 2013.

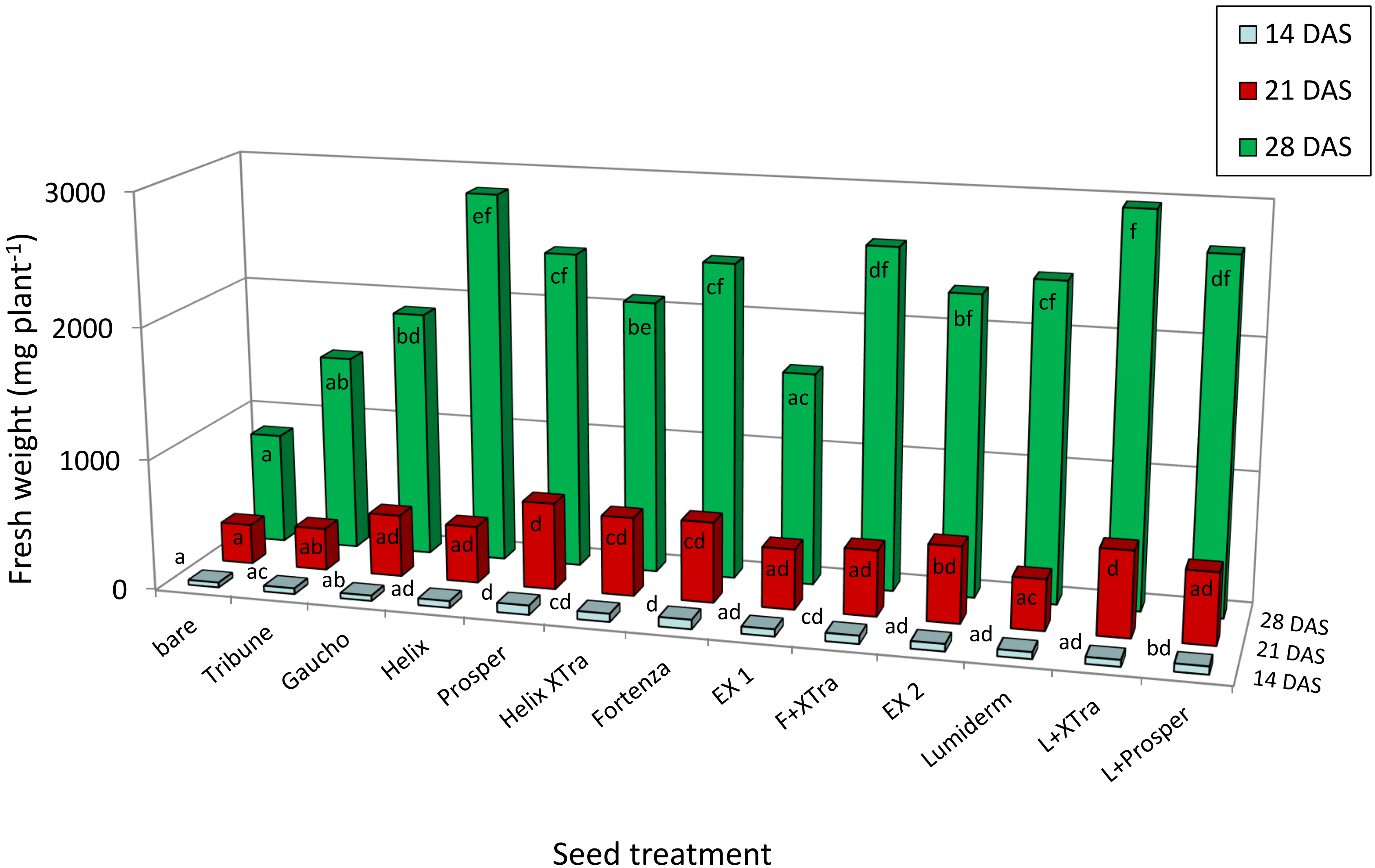


Fig. 44. Effect of seed treatments on fresh weight of canola mustard after 14, 21 and 28 days in 2013.

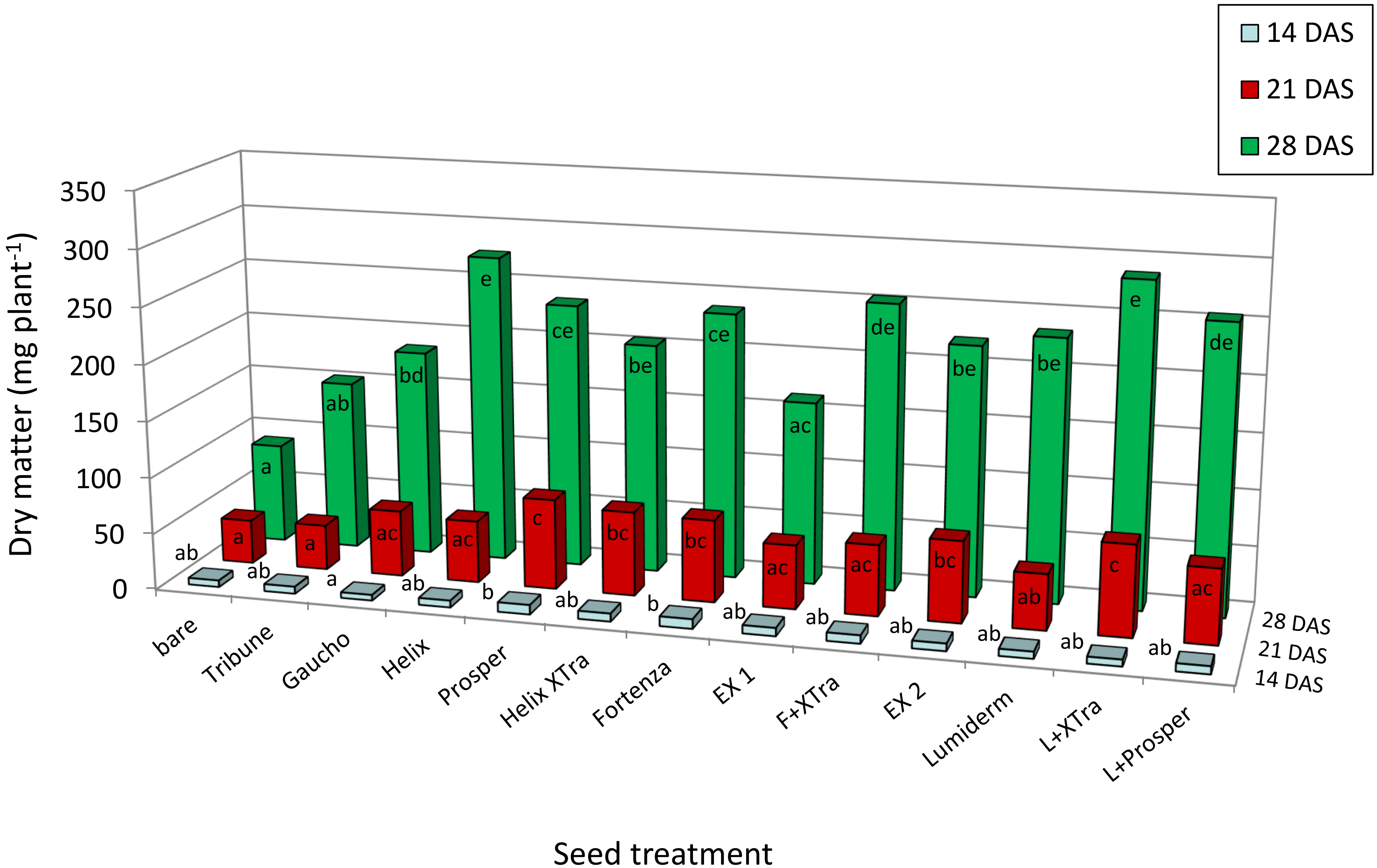


Fig. 45. Effect of seed treatments on dry matter content of canola mustard after 14, 21 and 28 days in 2013.

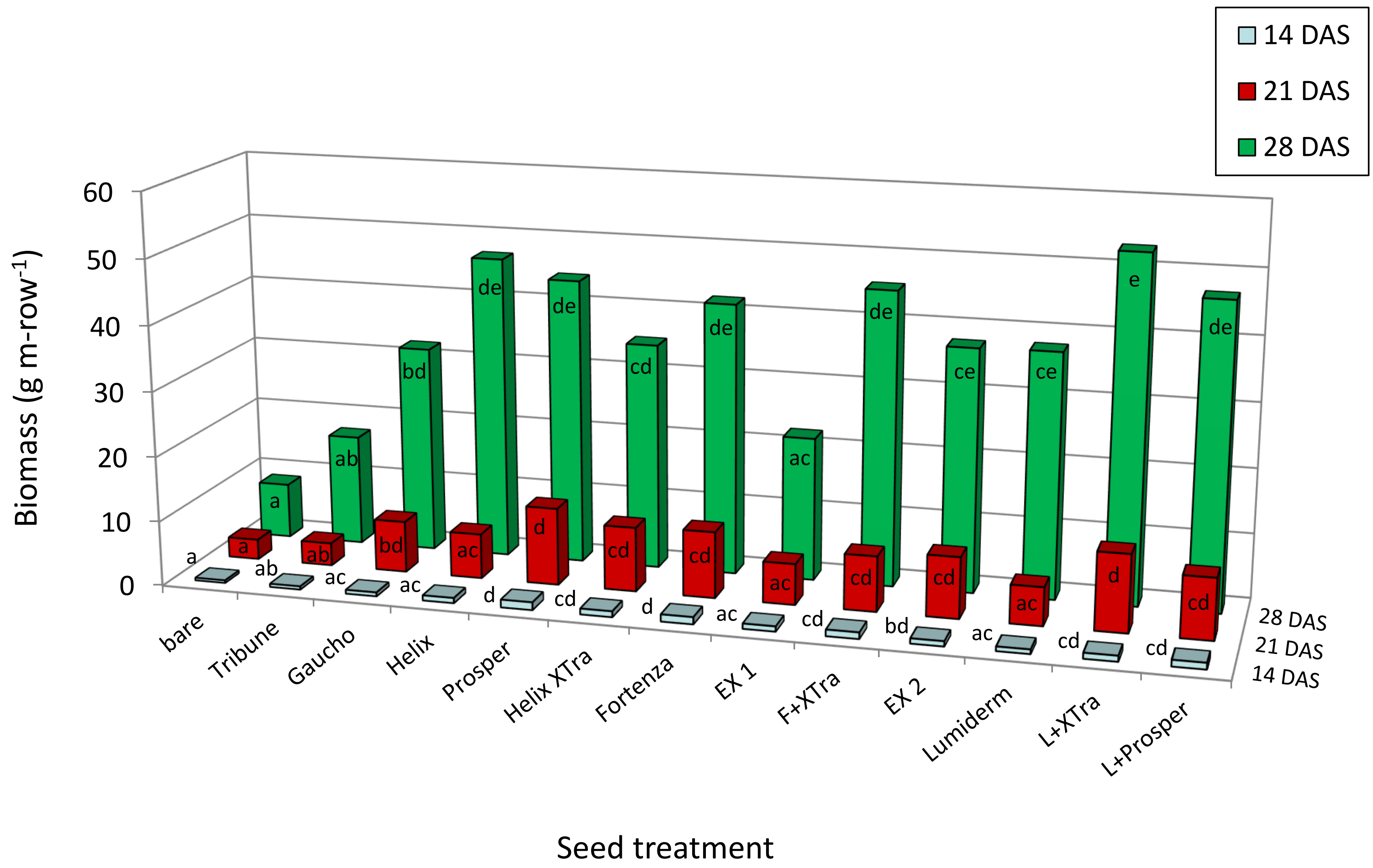


Fig. 46. Effect of seed treatments on biomass of canola mustard after 14, 21 and 28 days in 2013.

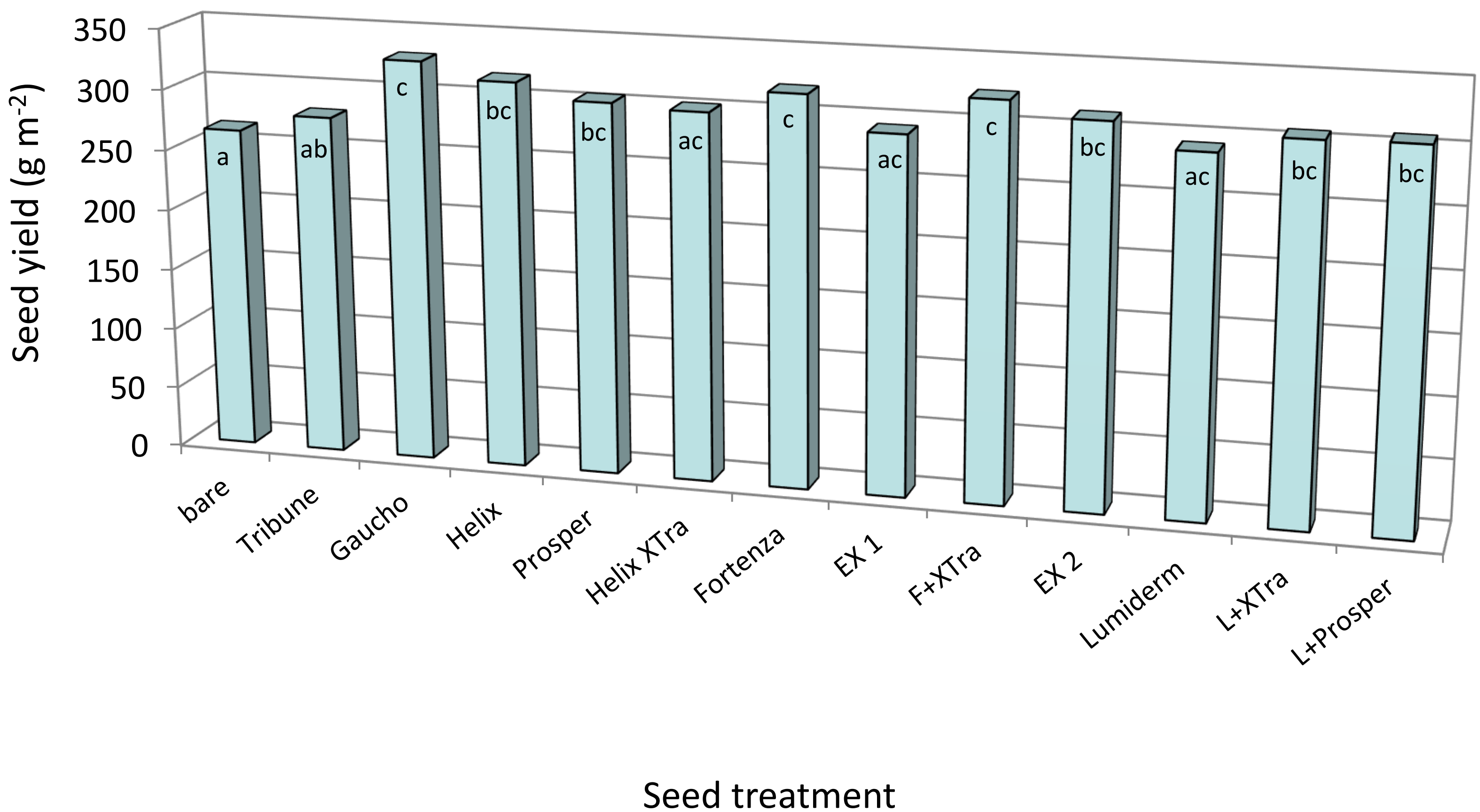


Fig. 47. Effect of seed treatments on seed yield of canola mustard in 2013.

Table 12. Ranking of seed treatments in field trial on canola mustard in 2013.

Treatment	Protection		Establishment	Biomass	Seed	
	14 DAS	21 DAS	21 DAS	28 DAS	yield	Overall
bare	13	12	13	13	13	13
Tribune	11	12	12	12	12	12
Gaucho CS FL	6	1	2	10	1	7
Helix	1	1	2	2	4	3
Prosper	1	1	2	2	4	3
Helix XTra	6	1	2	9	9	8
Fortenza (F)	10	1	2	2	1	6
EX 1	11	11	11	11	9	11
F + XTra mix	1	1	2	2	1	1
EX 2	6	1	9	7	4	8
Lumiderm (L)	6	1	10	7	9	10
L + XTra mix	1	1	1	1	4	2
L + Prosper mix	1	1	2	2	4	3

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 23.

Table 13. Air temperatures and rainfall at AAFC-Saskatoon in 2014.

Interval	Days after seeding hybrid canola[1]	Air temperatures (°C)			Rainfall(mm)
		minimum	maximum	average	
May		-4.8	30.9	10.1	61.1
June		1.0	25.4	14.1	94.8
	0-7	-4.0	19.7	9.2	17.6
	8-14	1.4	30.9	15.7	22.9
	15-21	3.0	24.1	13.9	19.7
	22-28	1.0	21.0	10.7	7.6

[1] Hybrid canola was seeded May 12. Canola mustard and leafhopper test on hybrid canola were seeded May 15.

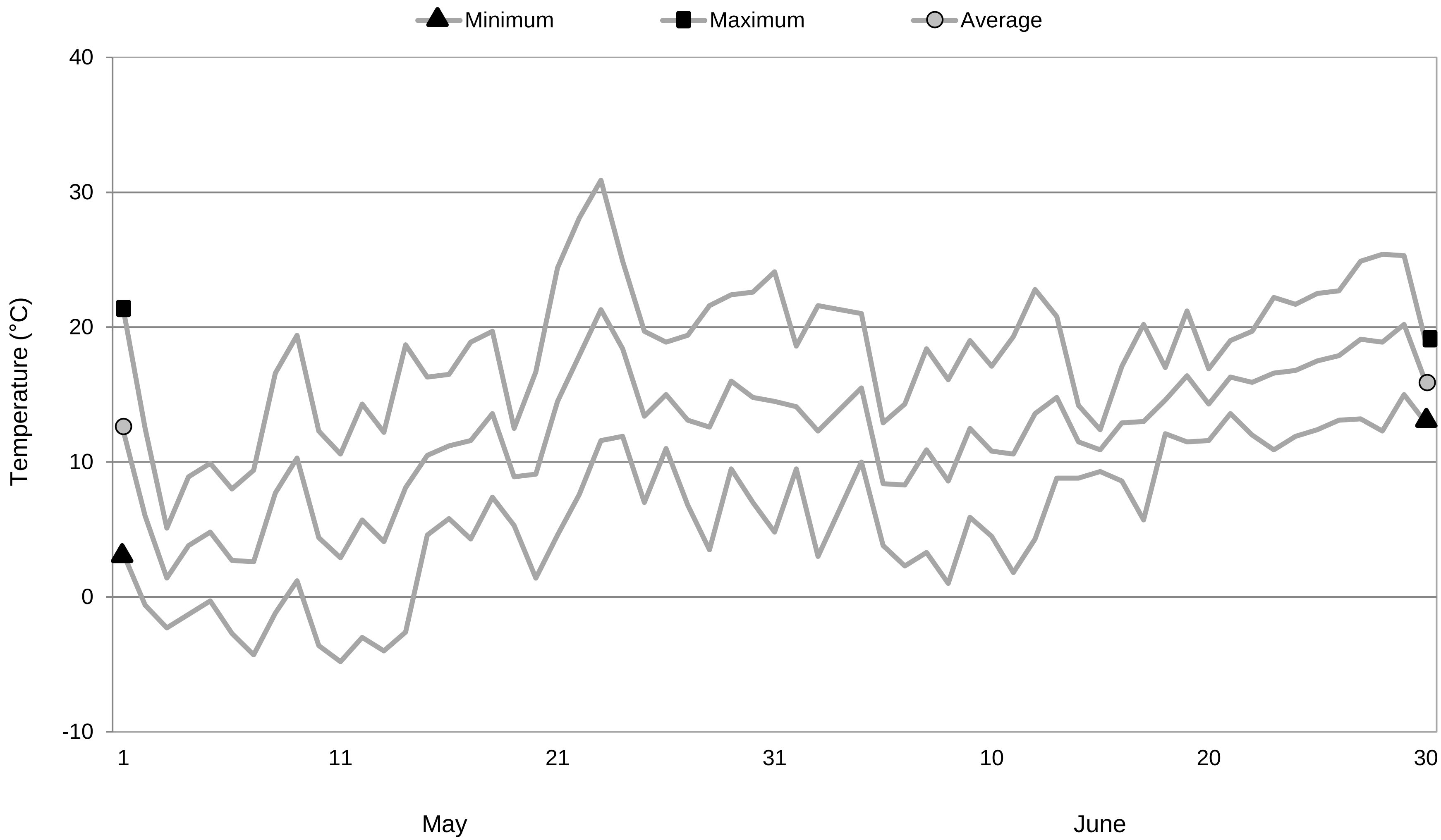


Fig. 48. Minimum, maximum and average daily air temperatures at Saskatoon in 2014.

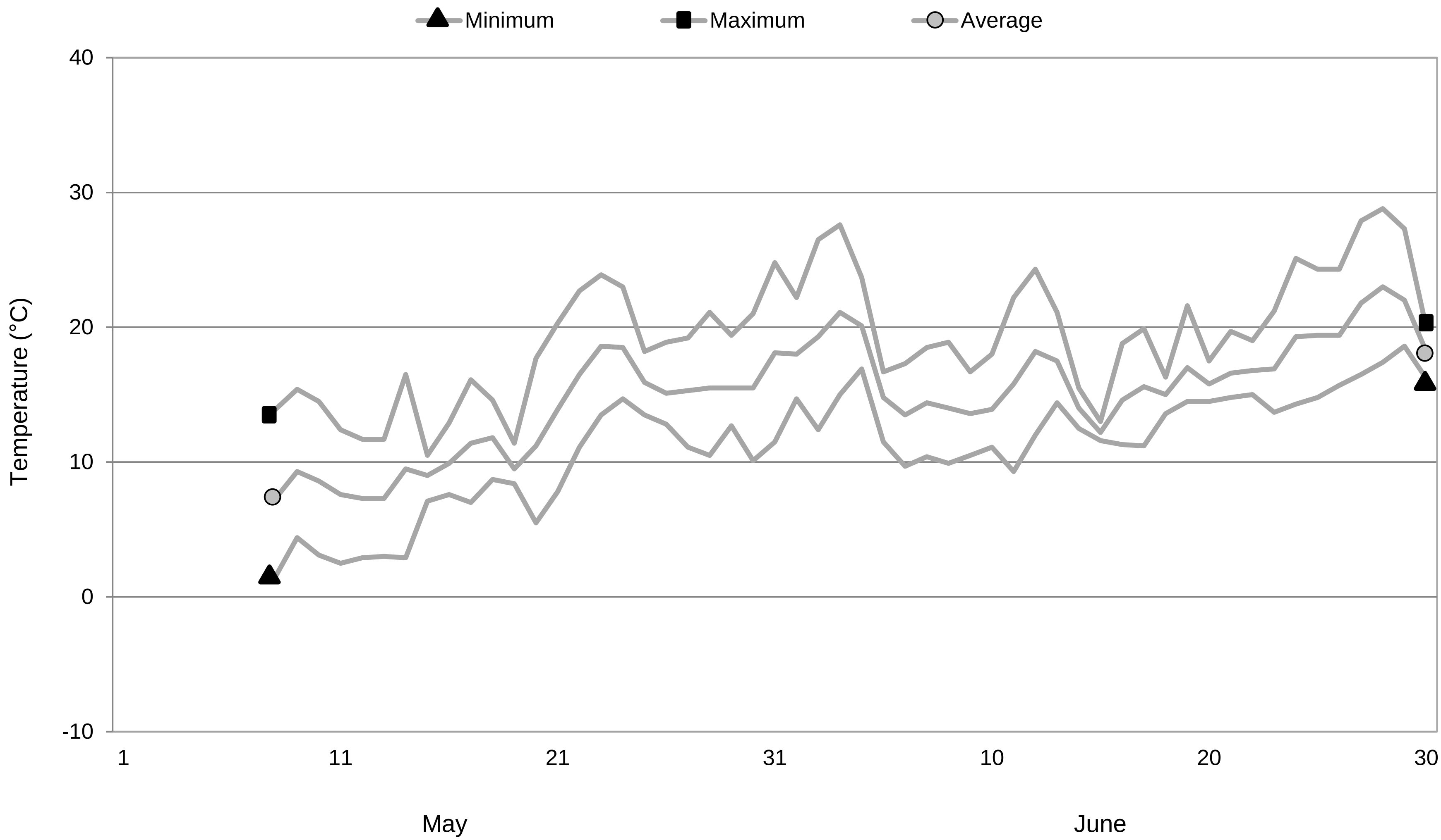


Fig. 49. Minimum, maximum and average daily soil temperatures (5 cm depth) at Saskatoon in 2014.

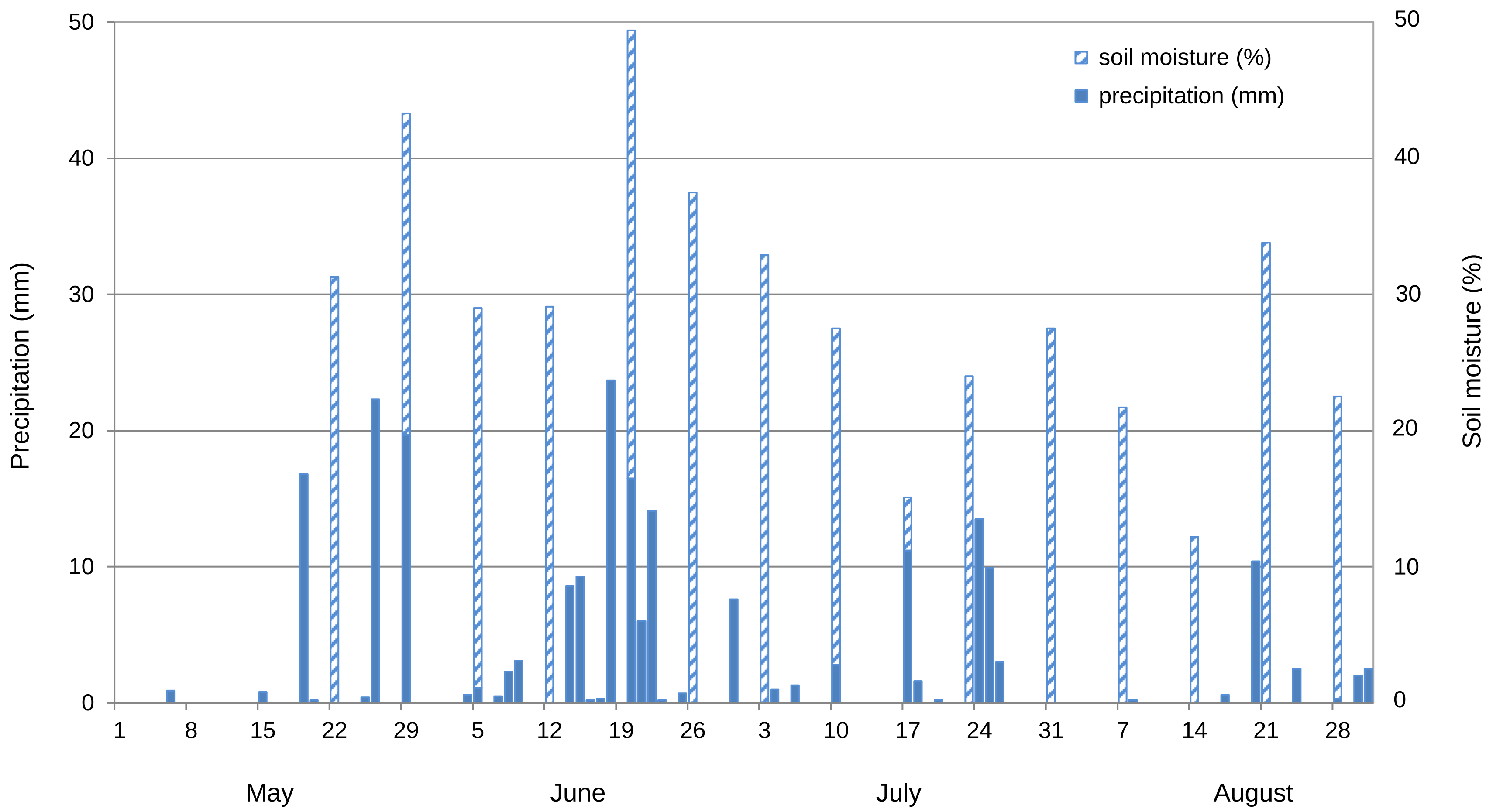


Fig. 50. Daily precipitation (solid bars) and soil moisture (hatched bars) at AAFC-Saskatoon in 2014.

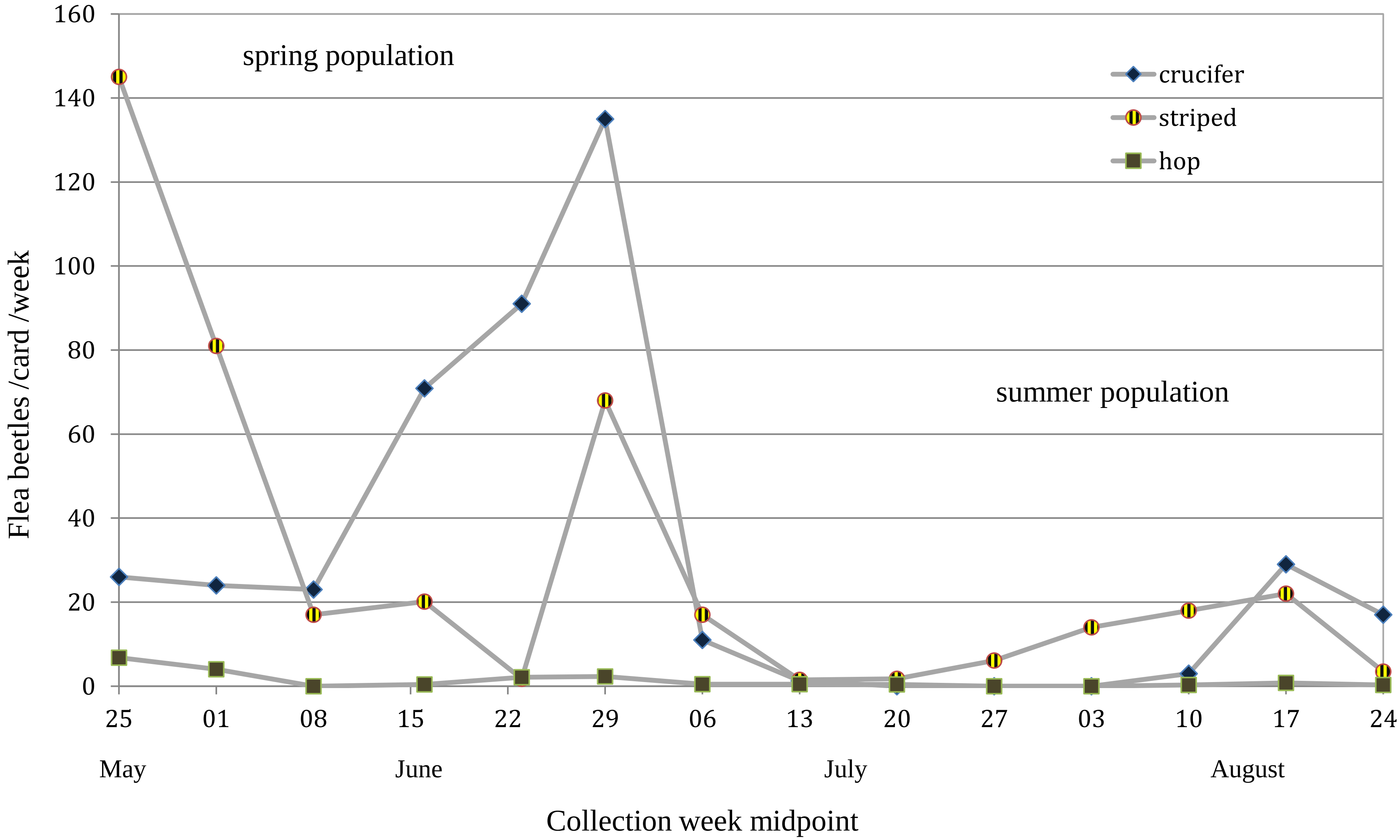


Fig. 51. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated Roundup Ready canola in 2014.

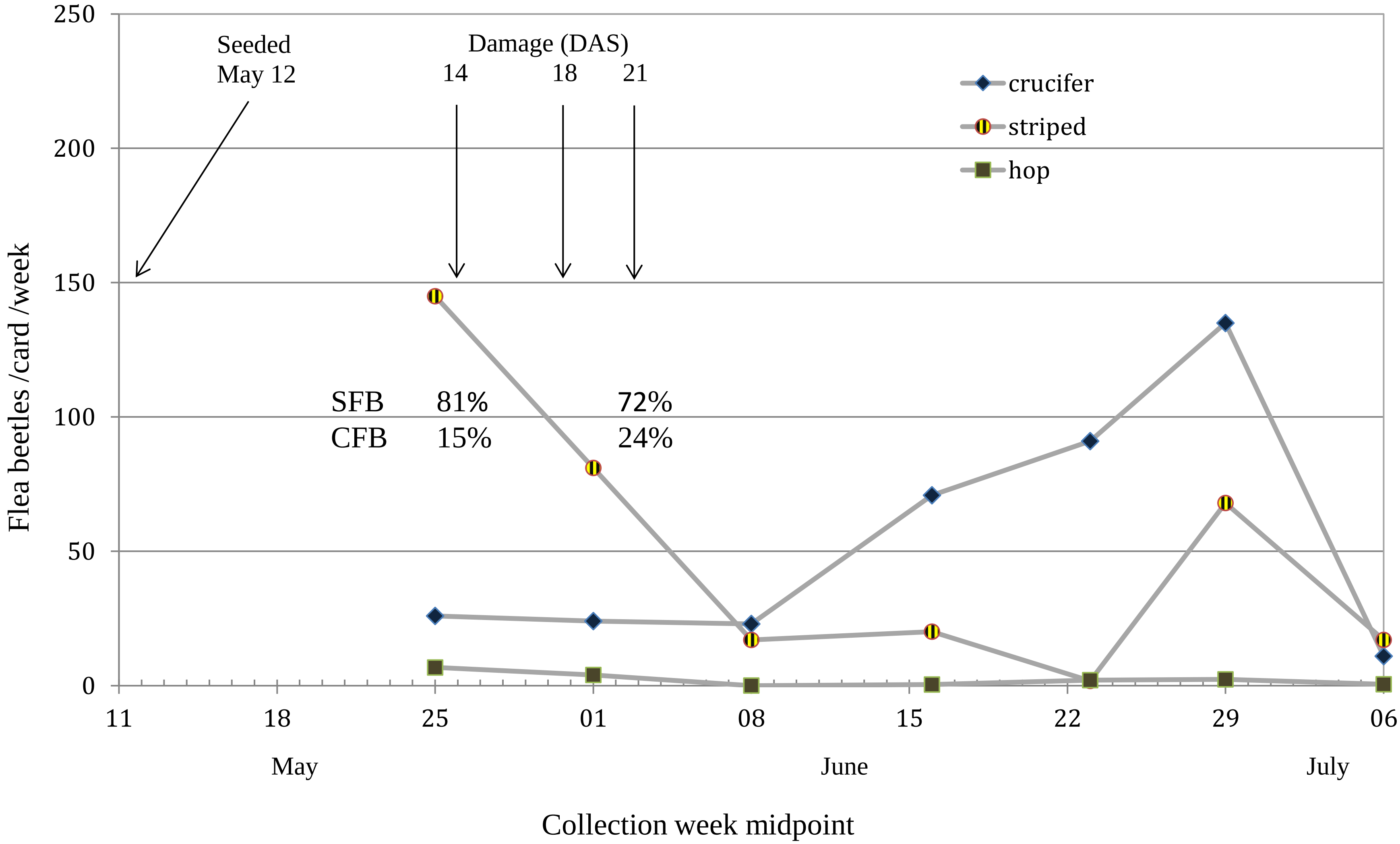


Fig. 52. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of Roundup Ready canola in 2014.

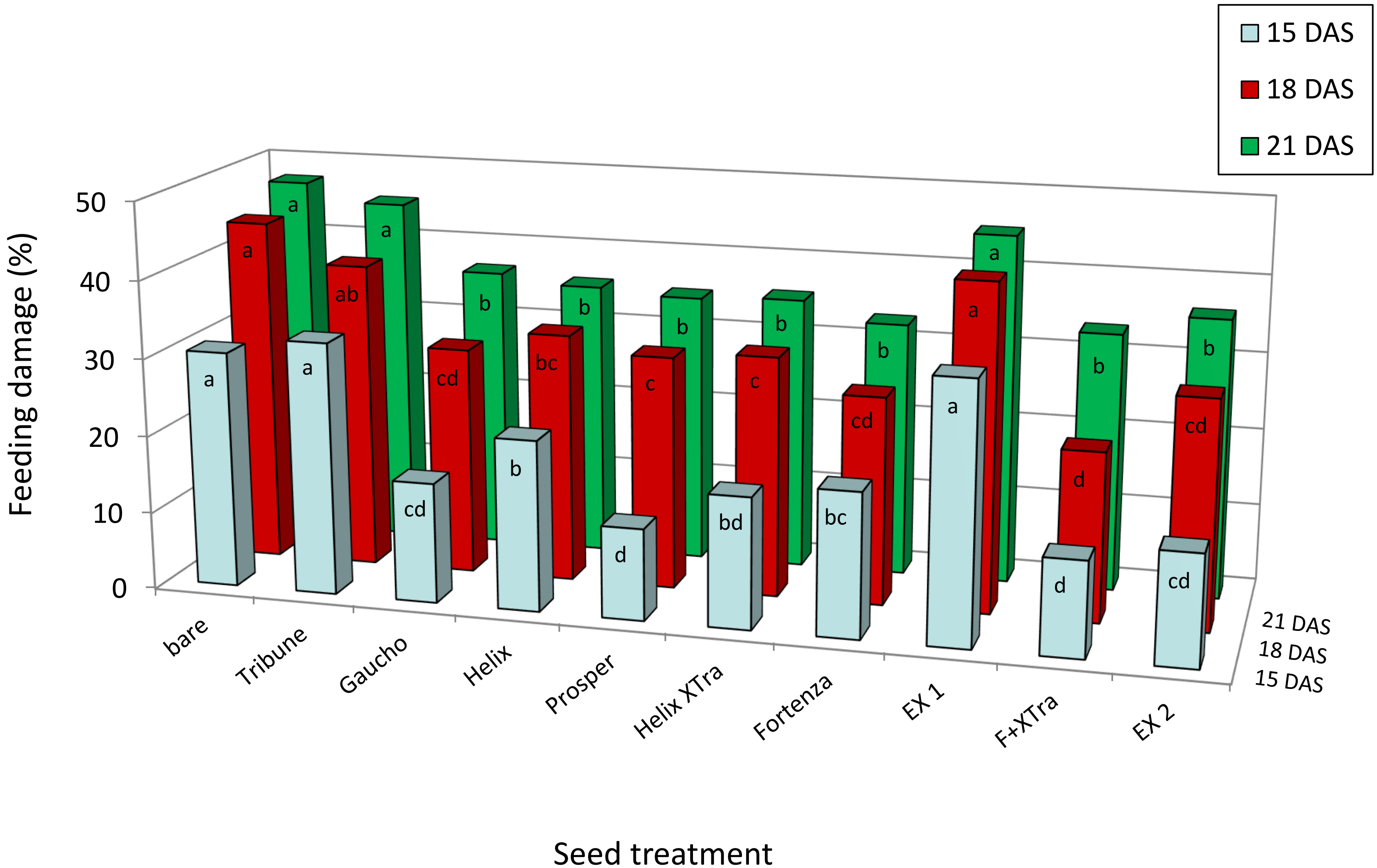


Fig. 53. Effect of seed treatments on flea beetle damage to Roundup Ready canola after 15, 18 and 21 days in 2014.

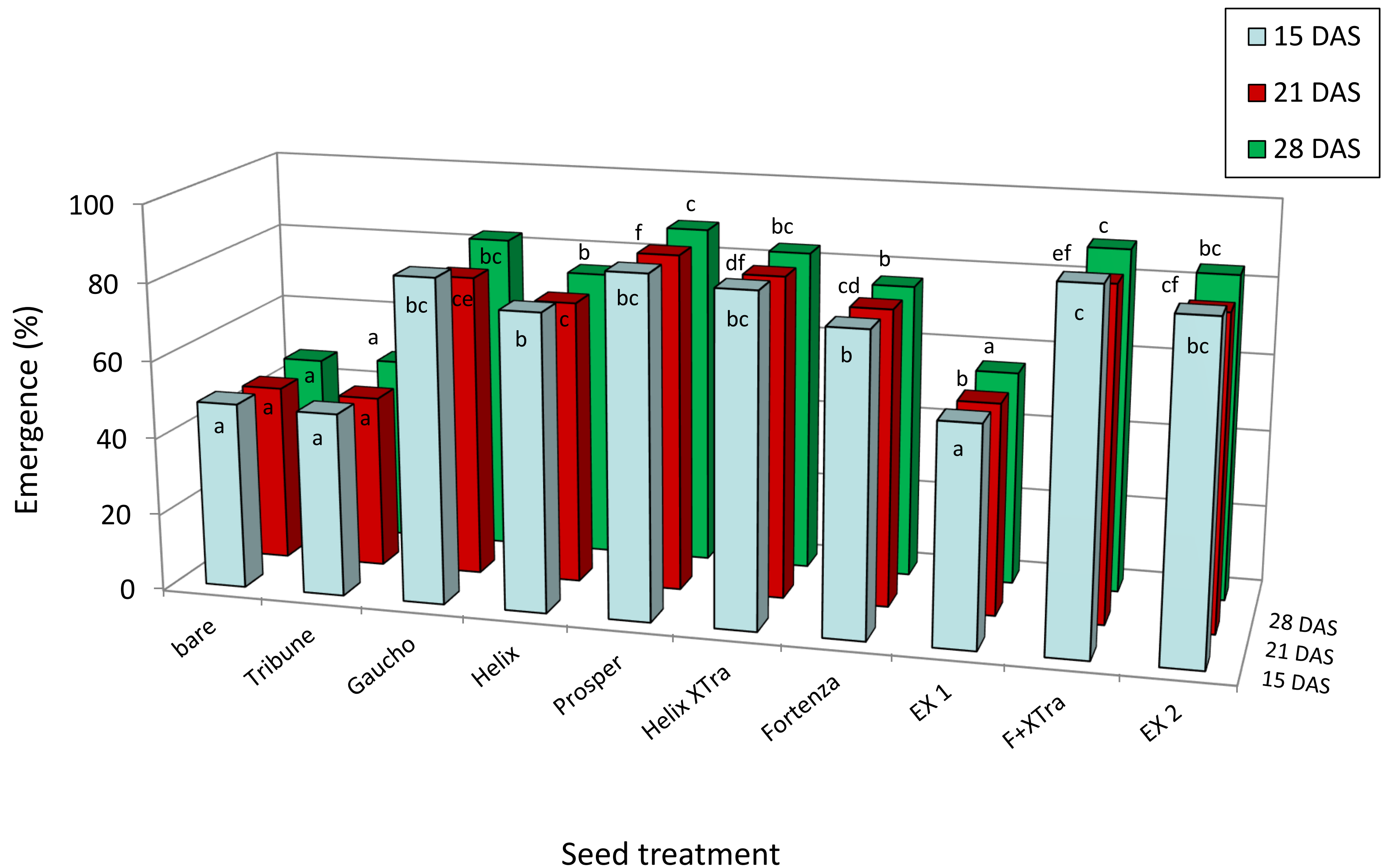


Fig. 54. Effect of seed treatments on emergence of Roundup Ready canola after 15, 21 and 28 days in 2014.

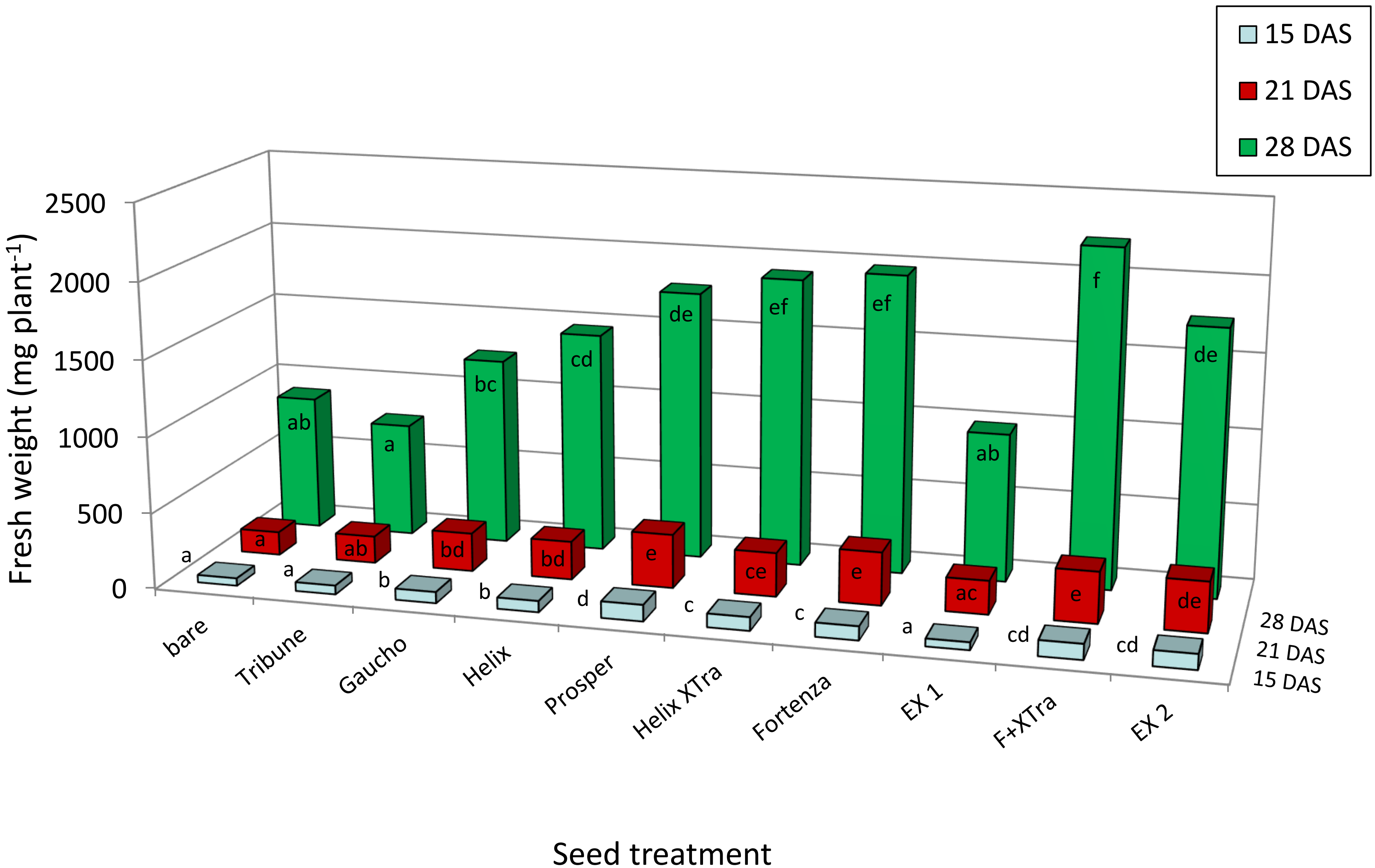


Fig. 55. Effect of seed treatments on fresh weight of Roundup Ready canola after 15, 21 and 28 days in 2014.

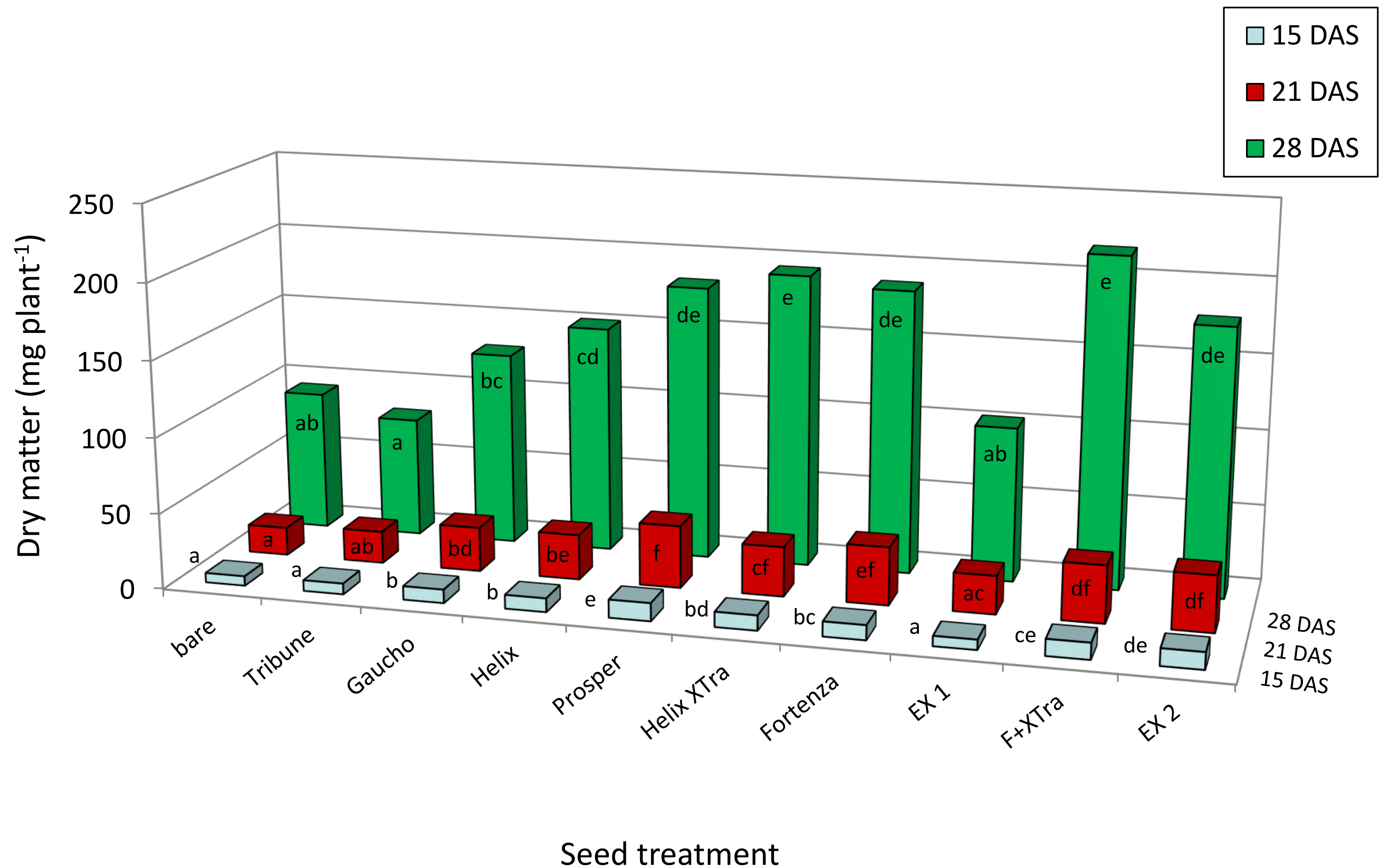


Fig. 56. Effect of seed treatments on dry matter content of Roundup Ready canola after 15, 21 and 28 days in 2014.

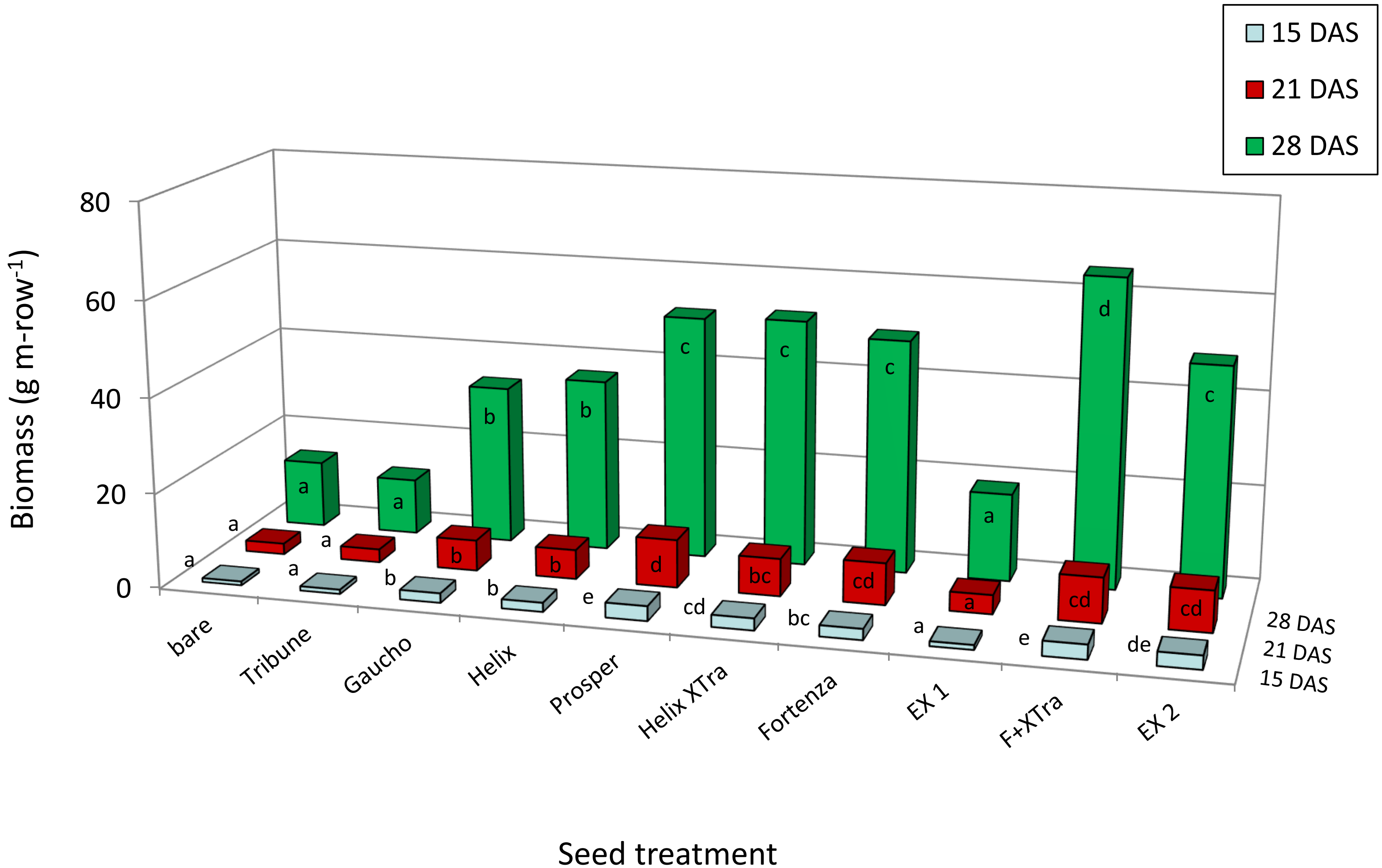


Fig. 57. Effect of seed treatments on biomass of Roundup Ready canola after 15, 21 and 28 days in 2014.

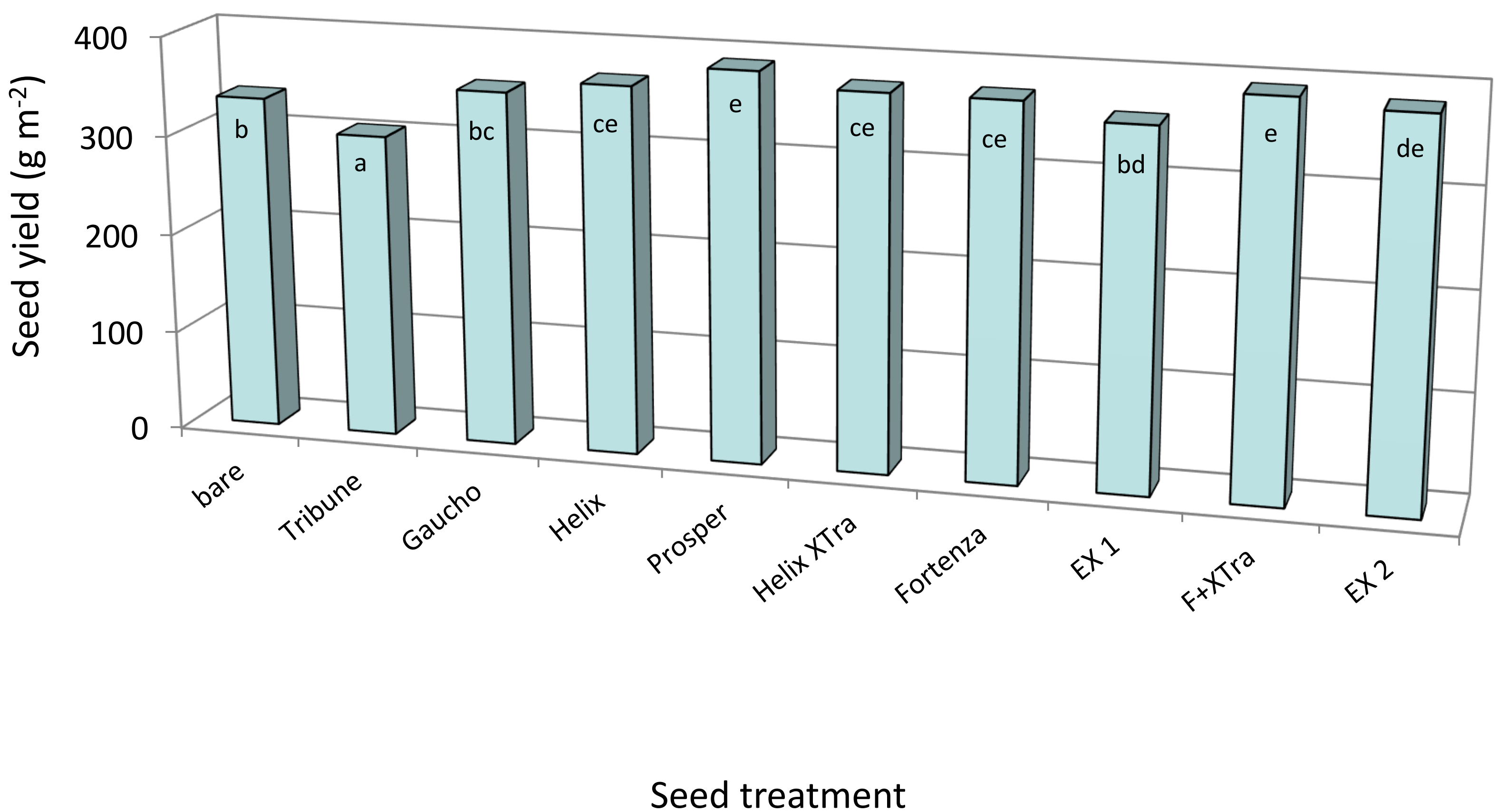


Fig. 58. Effect of seed treatments on seed yield of Roundup Ready canola in 2014.

Table 14. Ranking of seed treatments in field trial on Roundup Ready canola in 2014.

Treatment	Protection 15 DAS	Protection 21 DAS	Establishment 21 DAS	Biomass 28 DAS	Seed yield	Overall
bare	8	8	9	9	9	9
Tribune	8	8	9	9	10	10
Gaucho CS FL	3	1	5	7	8	6
Helix	7	1	7	7	4	7
Prosper	1	1	1	2	1	1
Helix XTra	5	1	3	2	4	4
Fortenza (F)	5	1	6	2	4	5
EX 1	8	8	8	2	7	8
F + XTra mix	1	1	2	1	1	1
EX 2	3	1	4	2	3	3

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 12.

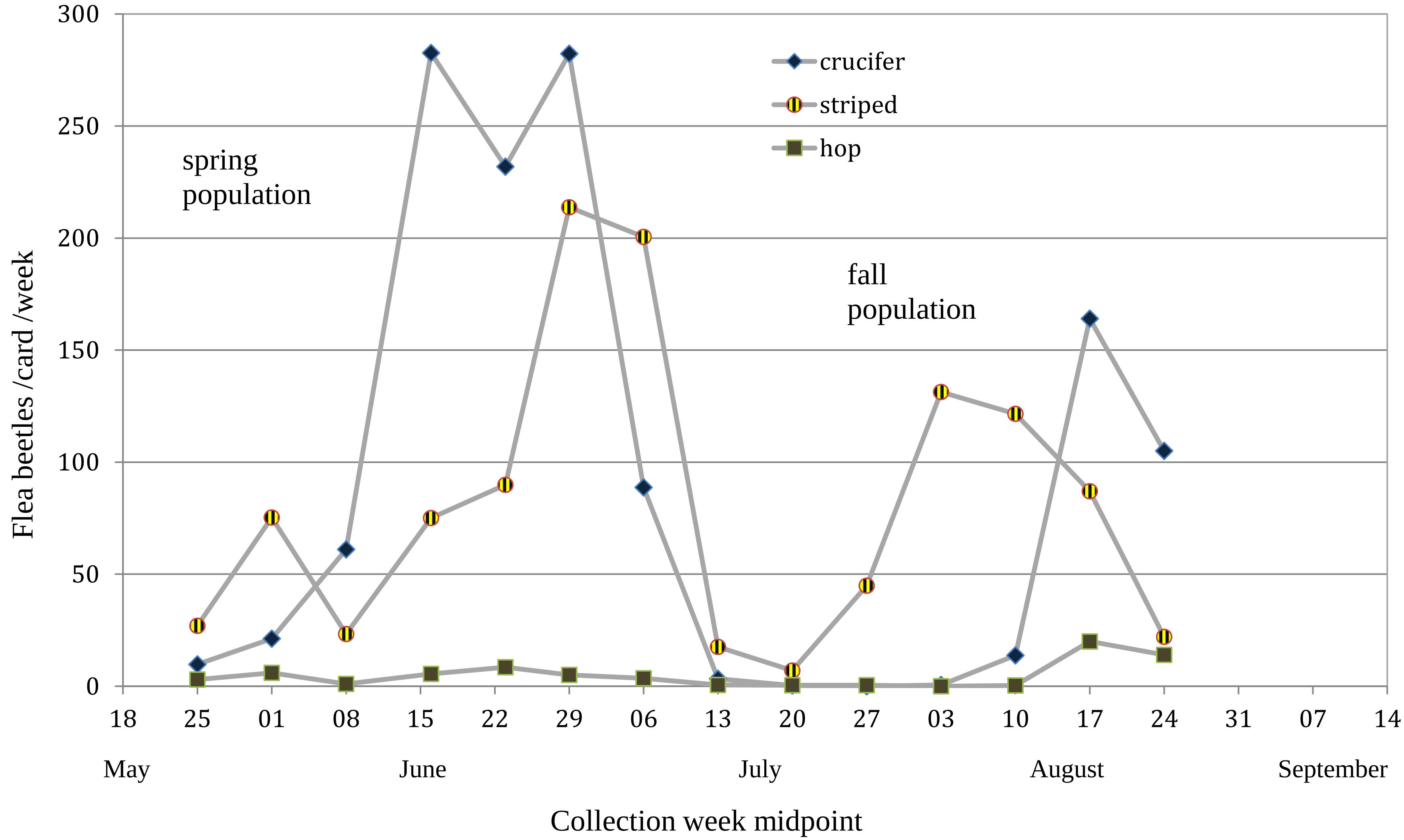


Fig. 59. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated canola mustard in 2014.

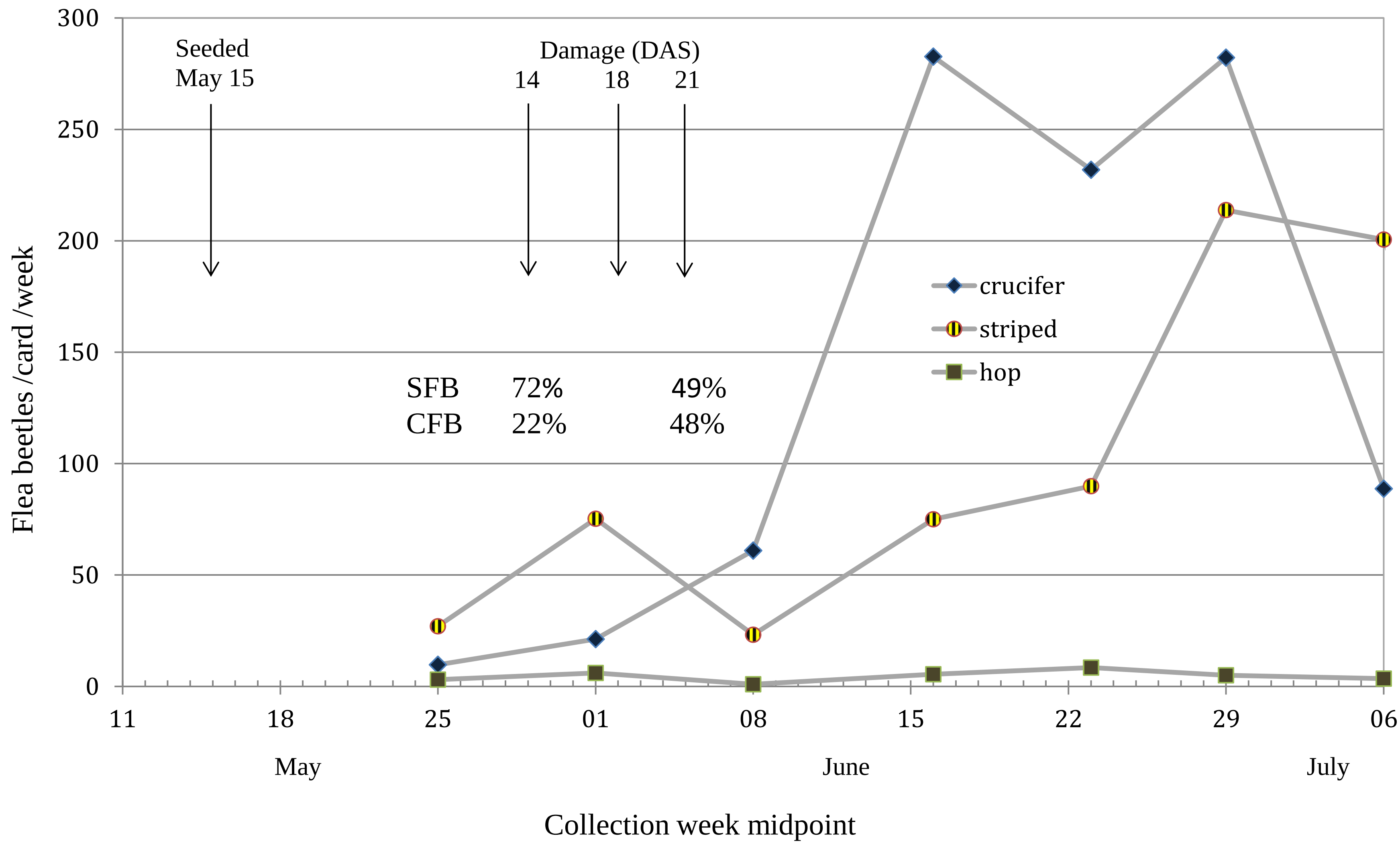


Fig. 60. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of canola mustard in 2014.

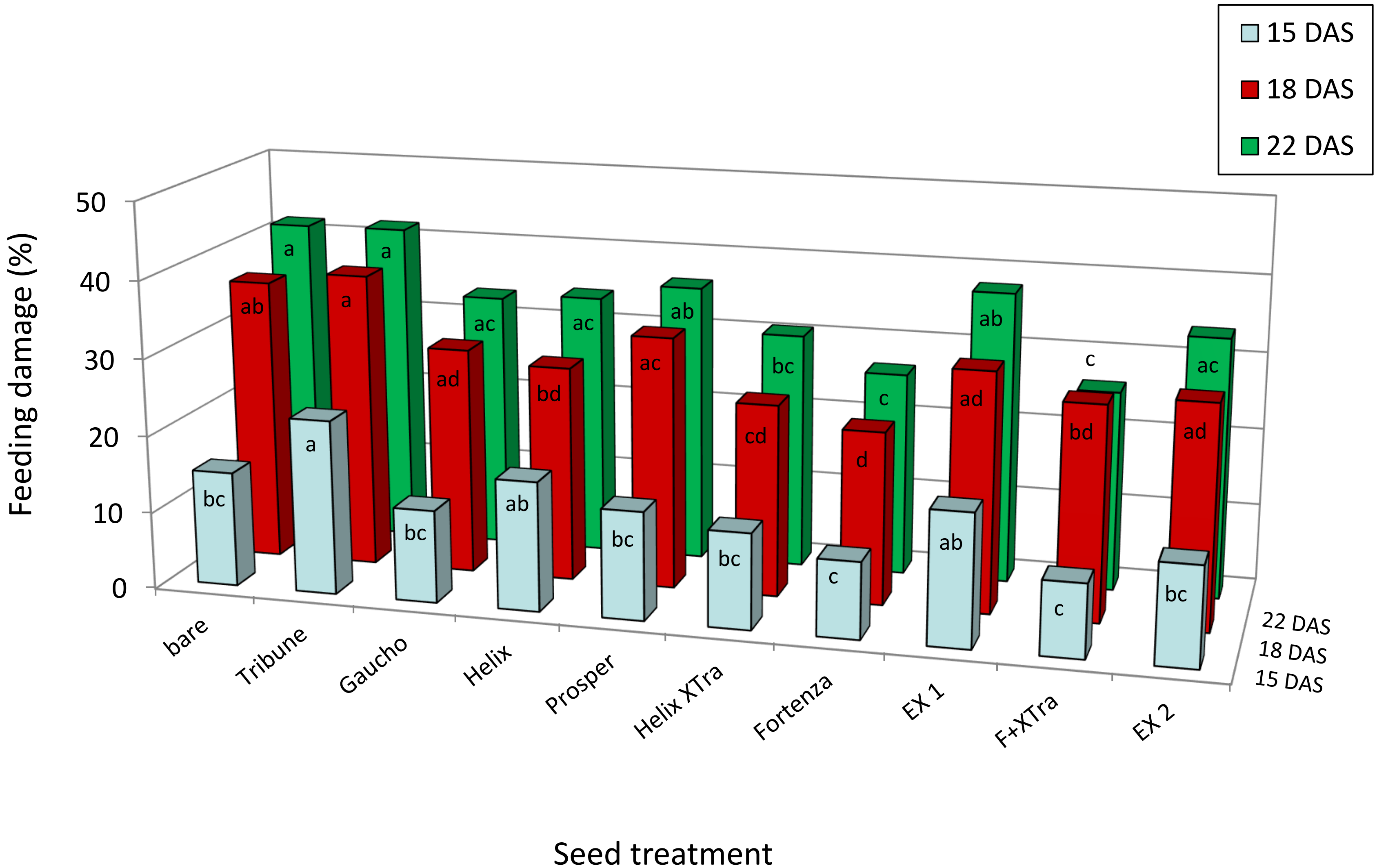


Fig. 61. Effect of seed treatments on flea beetle damage to canola mustard after 15, 18 and 22 days in 2014.

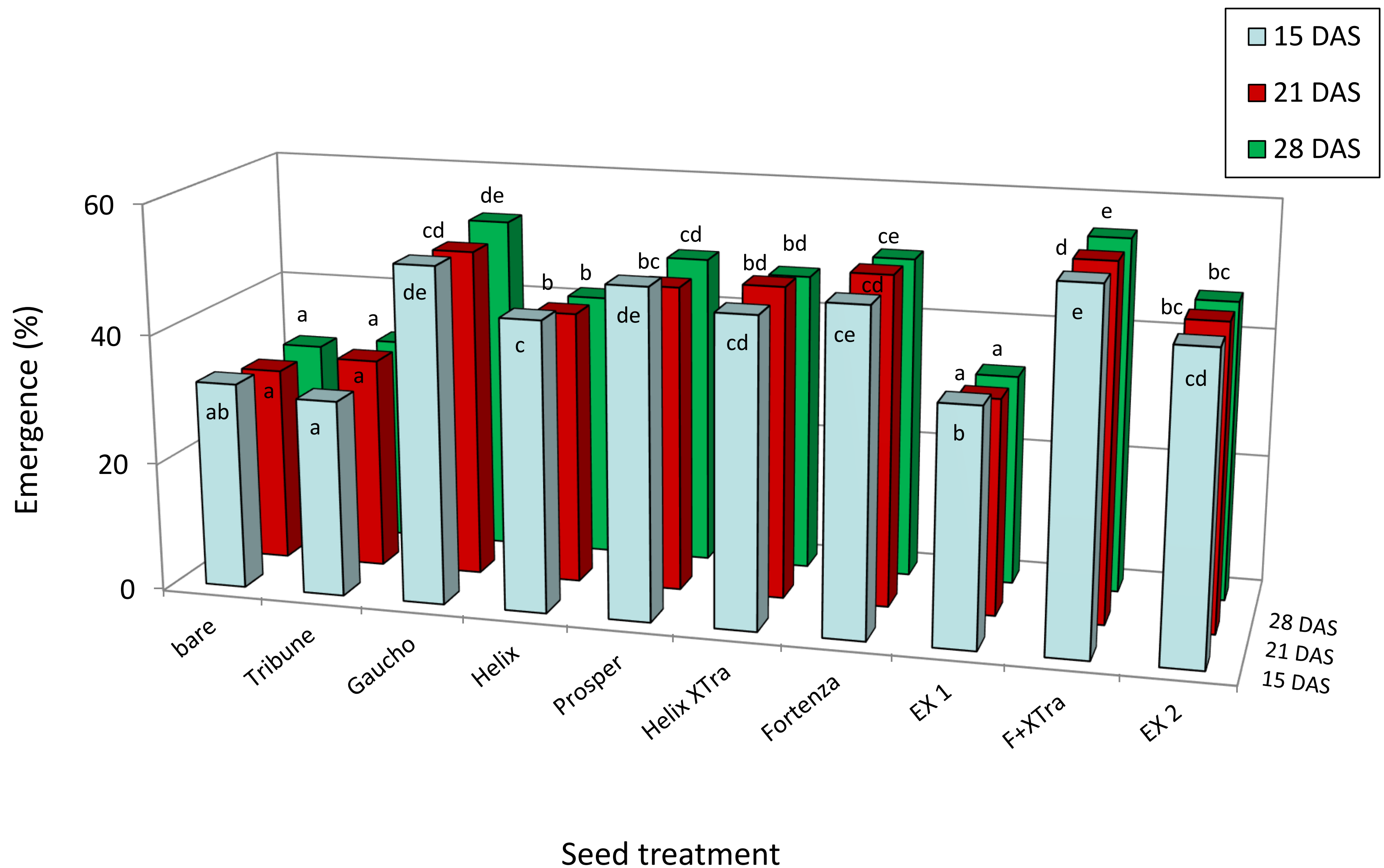


Fig. 62. Effect of seed treatments on emergence of canola mustard after 15, 21 and 28 days in 2014.

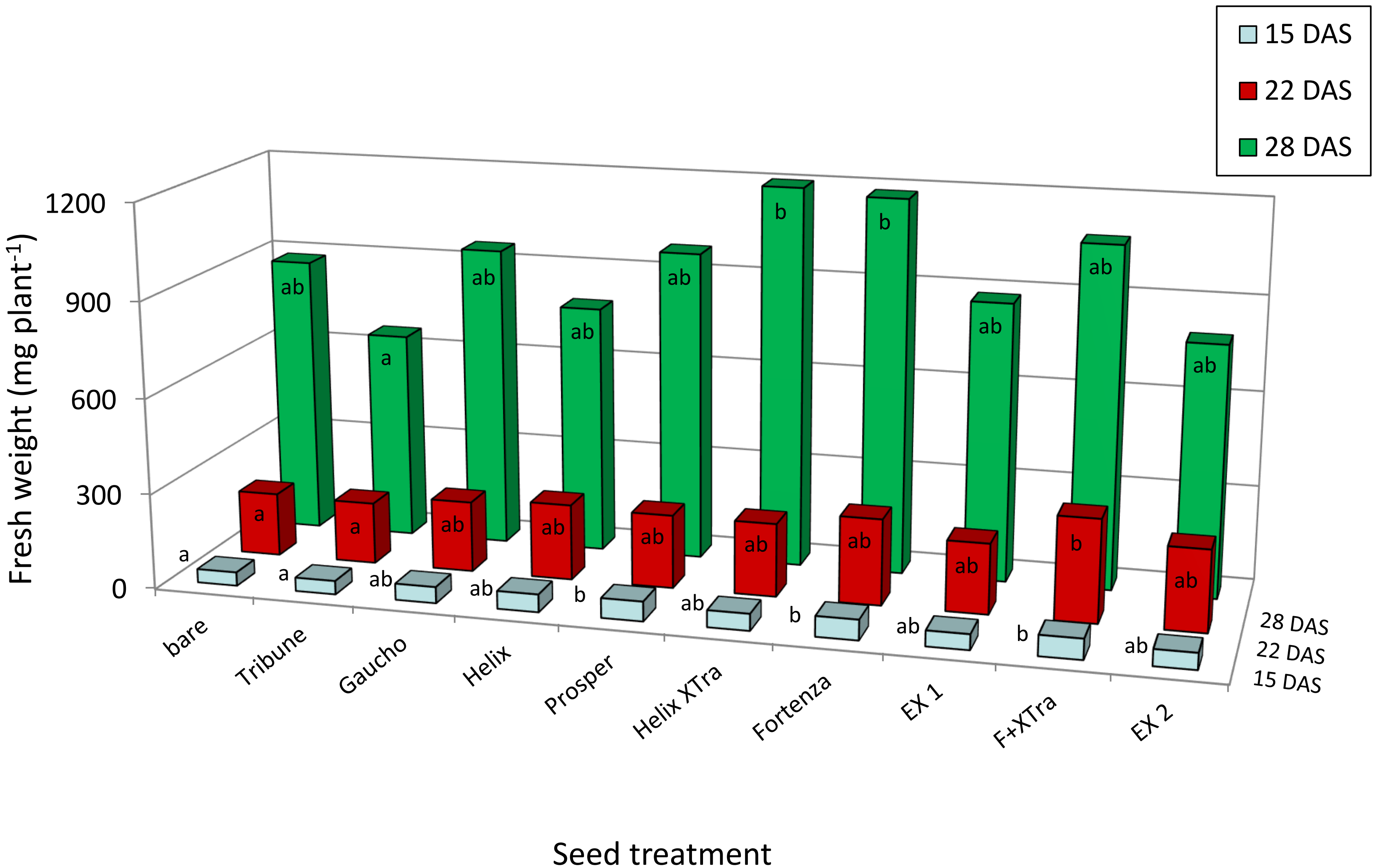


Fig. 63. Effect of seed treatments on fresh weight of canola mustard after 15, 22 and 28 days in 2014.

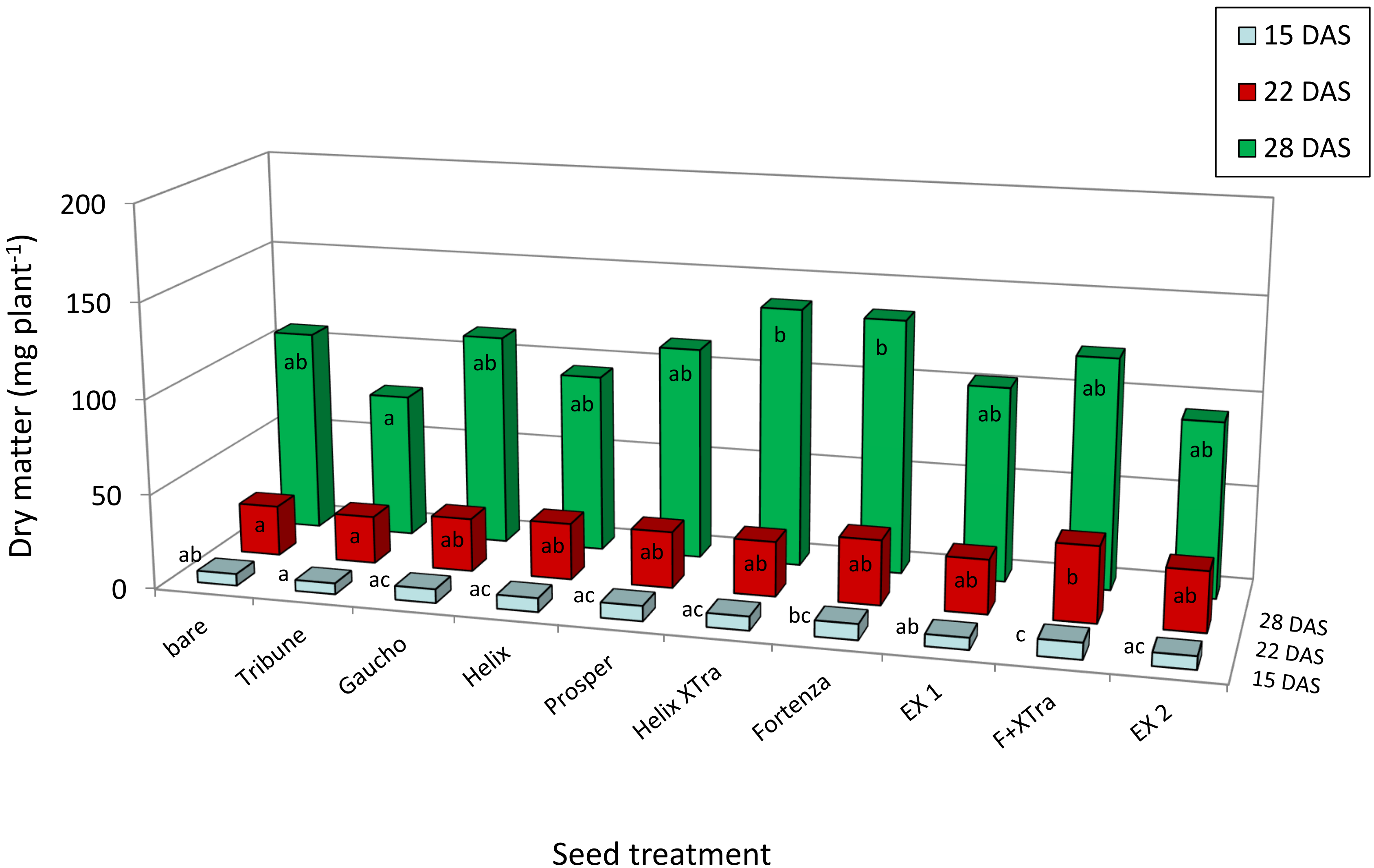


Fig. 64. Effect of seed treatments on dry matter content of canola mustard after 15, 22 and 28 days in 2014.

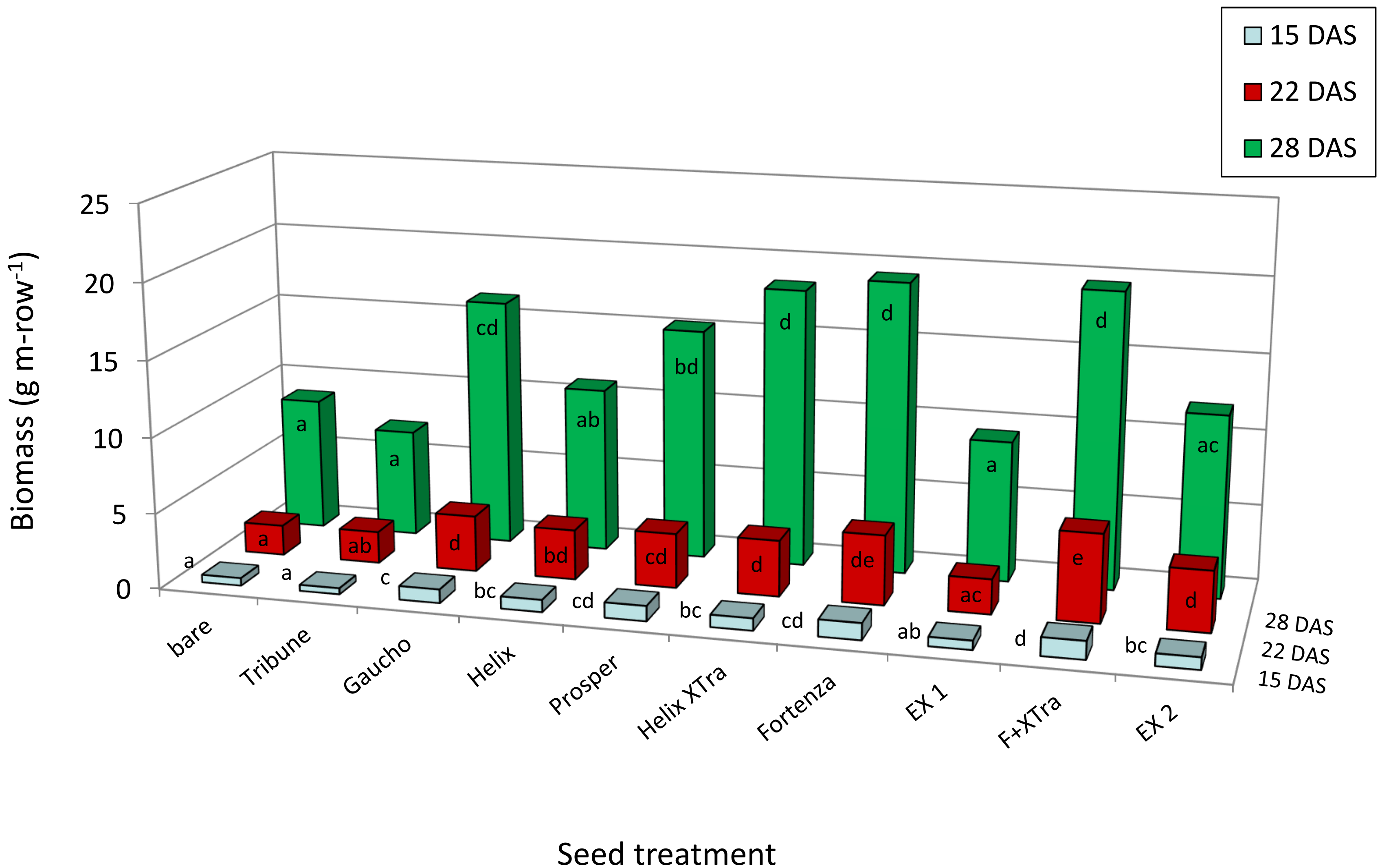


Fig. 65. Effect of seed treatments on biomass of canola mustard after 15, 22 and 28 days in 2014.

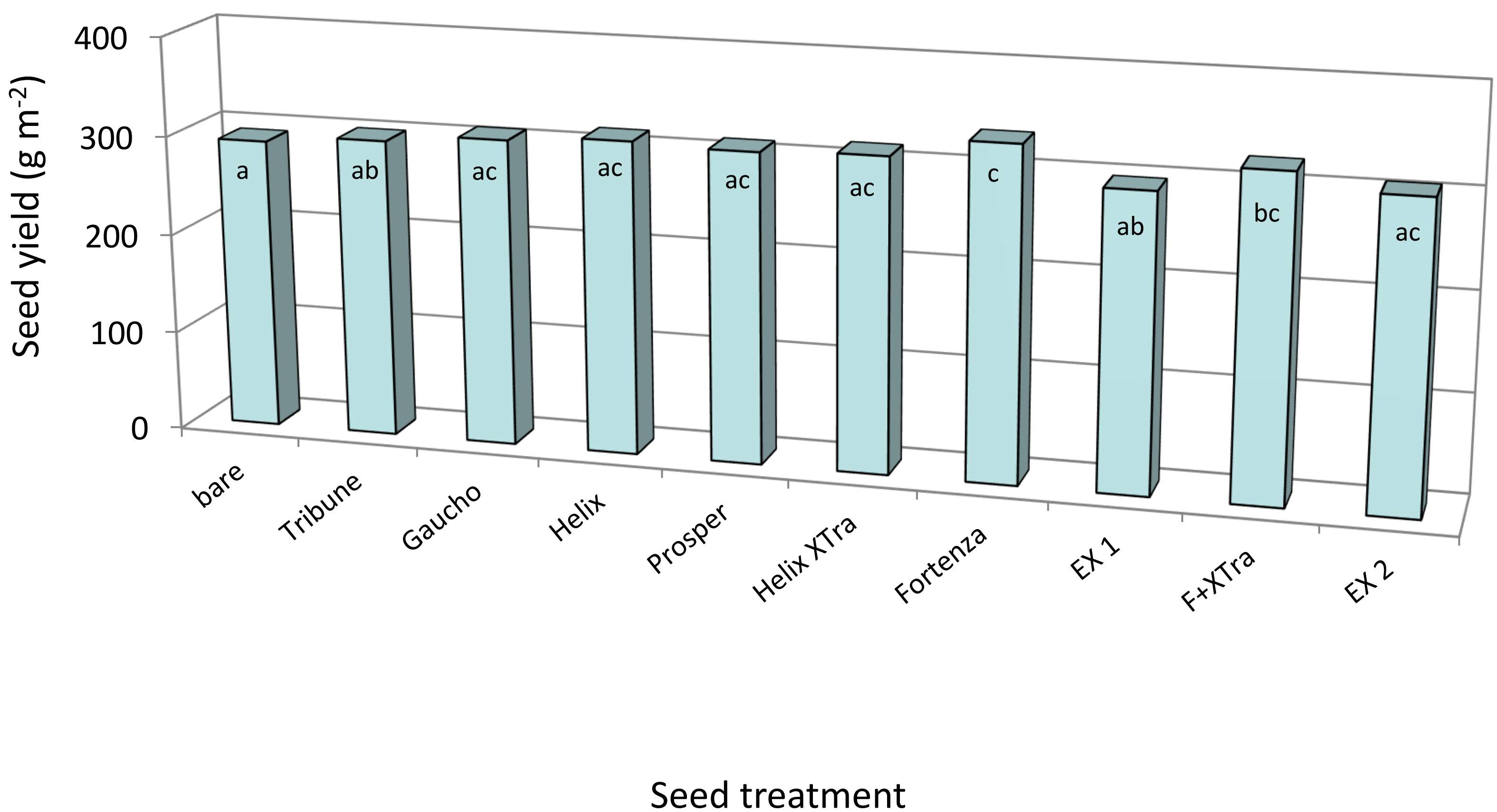


Fig. 66. Effect of seed treatments on seed yield of canola mustard in 2014.

Table 15. Ranking of seed treatments in field trial on canola mustard in 2014.

Treatment	Protection		Establishment	Biomass	Seed	
	15 DAS	21 DAS	21 DAS	28 DAS	yield	Overall
bare	3	9	8	8	10	8
Tribune	10	9	8	8	8	10
Gaucho CS FL	3	4	2	4	8	4
Helix	8	4	7	7	3	7
Prosper	3	7	5	5	3	5
Helix XTra	3	3	4	1	3	3
Fortenza (F)	1	1	2	1	1	1
EX 1	8	7	8	8	8	9
F + XTra mix	1	1	1	1	2	1
EX 2	3	4	5	6	3	6

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 12.

Table 16. Air temperatures and rainfall at AAFC-Saskatoon in 2015.

Interval	Days after seeding[1]	Air temperatures (°C) min.	max.	average	Rainfall(mm)
May		-5.7	28.9	10.1	0.4
June		2.3	33.4	17.2	13.6
	0-7	-5.7	23.9	8.9	0.0
	8-14	4.6	28.9	16.6	0.0
	15-21	-2.8	24.0	11.3	0.0
	22-28	7.3	33.3	18.6	0.0

[1] Field test seeded May 13.

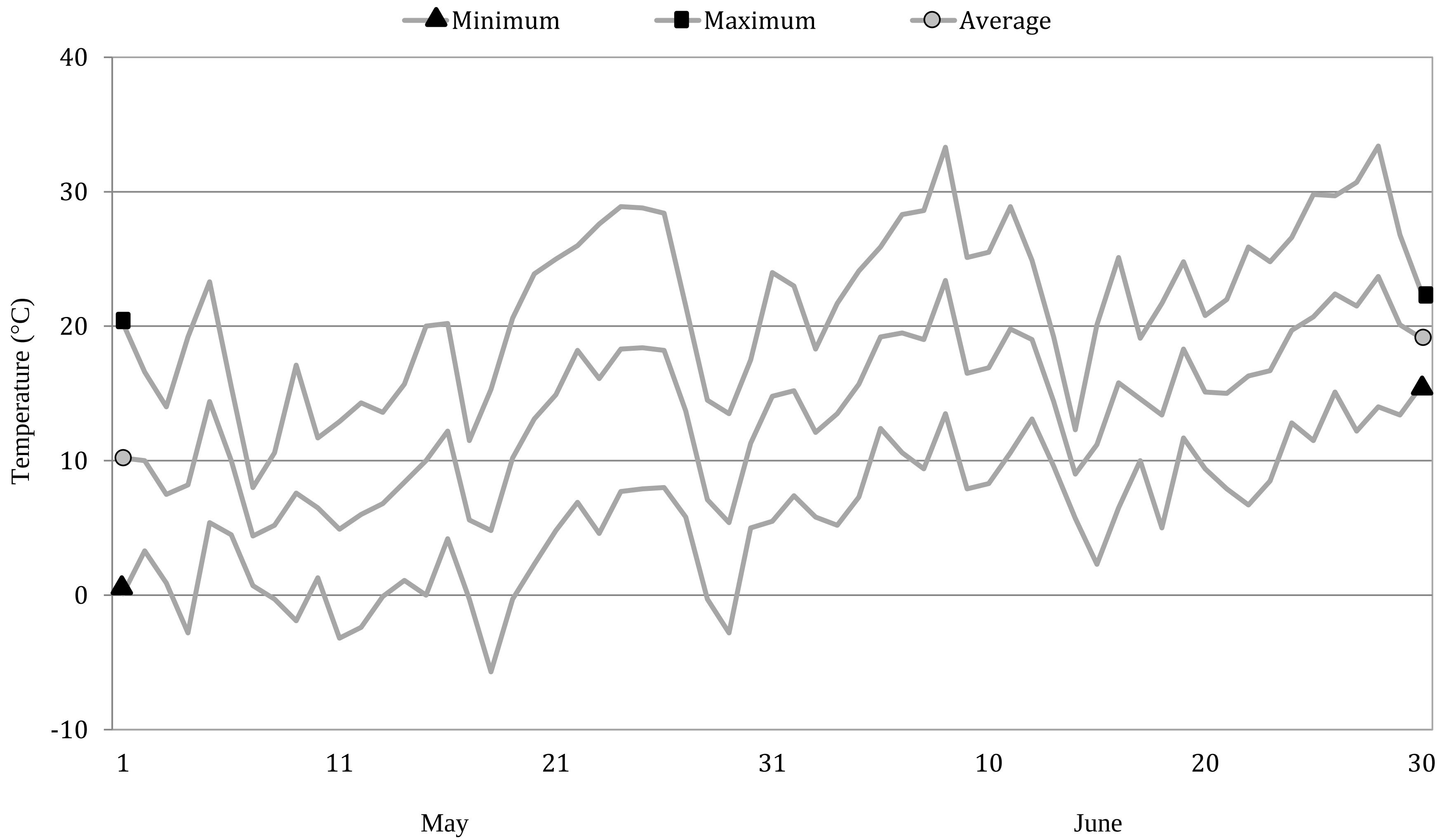


Fig. 67. Minimum, maximum and average daily air temperatures at Saskatoon in 2015.

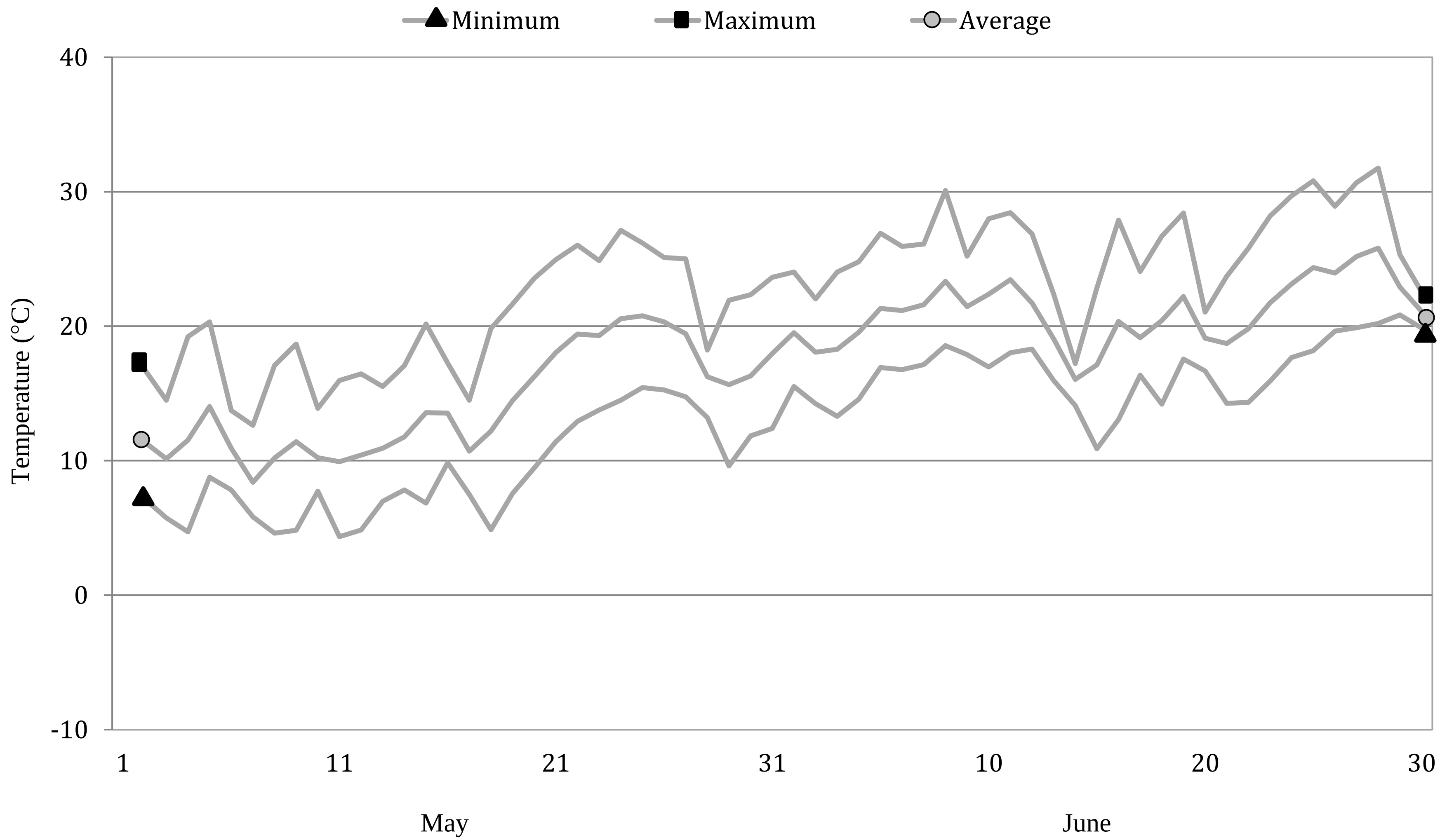


Fig. 68. Minimum, maximum and average daily soil temperatures (5 cm depth) at Saskatoon in 2015.

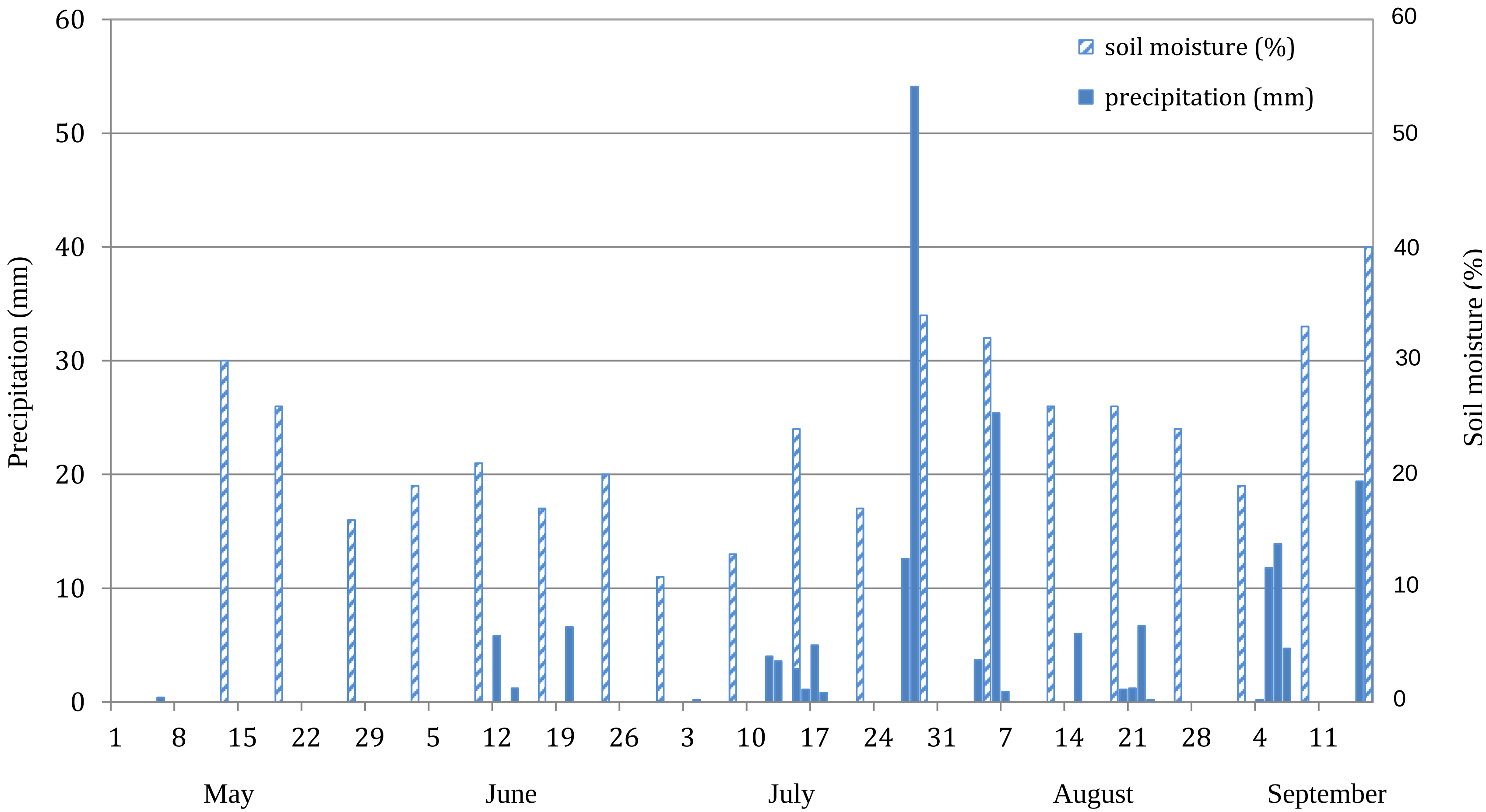


Fig. 69. Daily precipitation (solid bars) and soil moisture (hatched bars) at AAFC-Saskatoon in 2015.

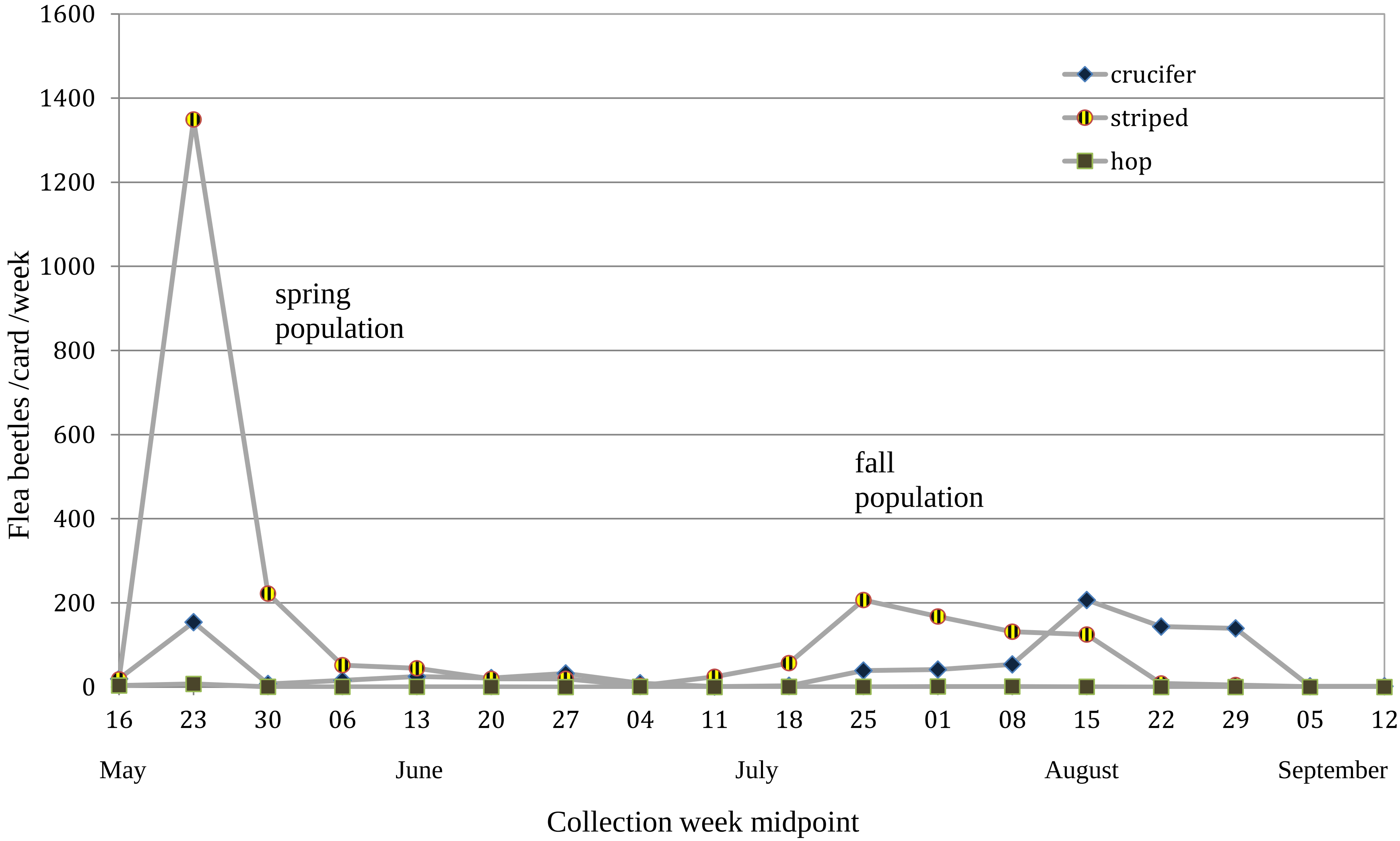


Fig. 70. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated Roundup Ready canola in 2015.

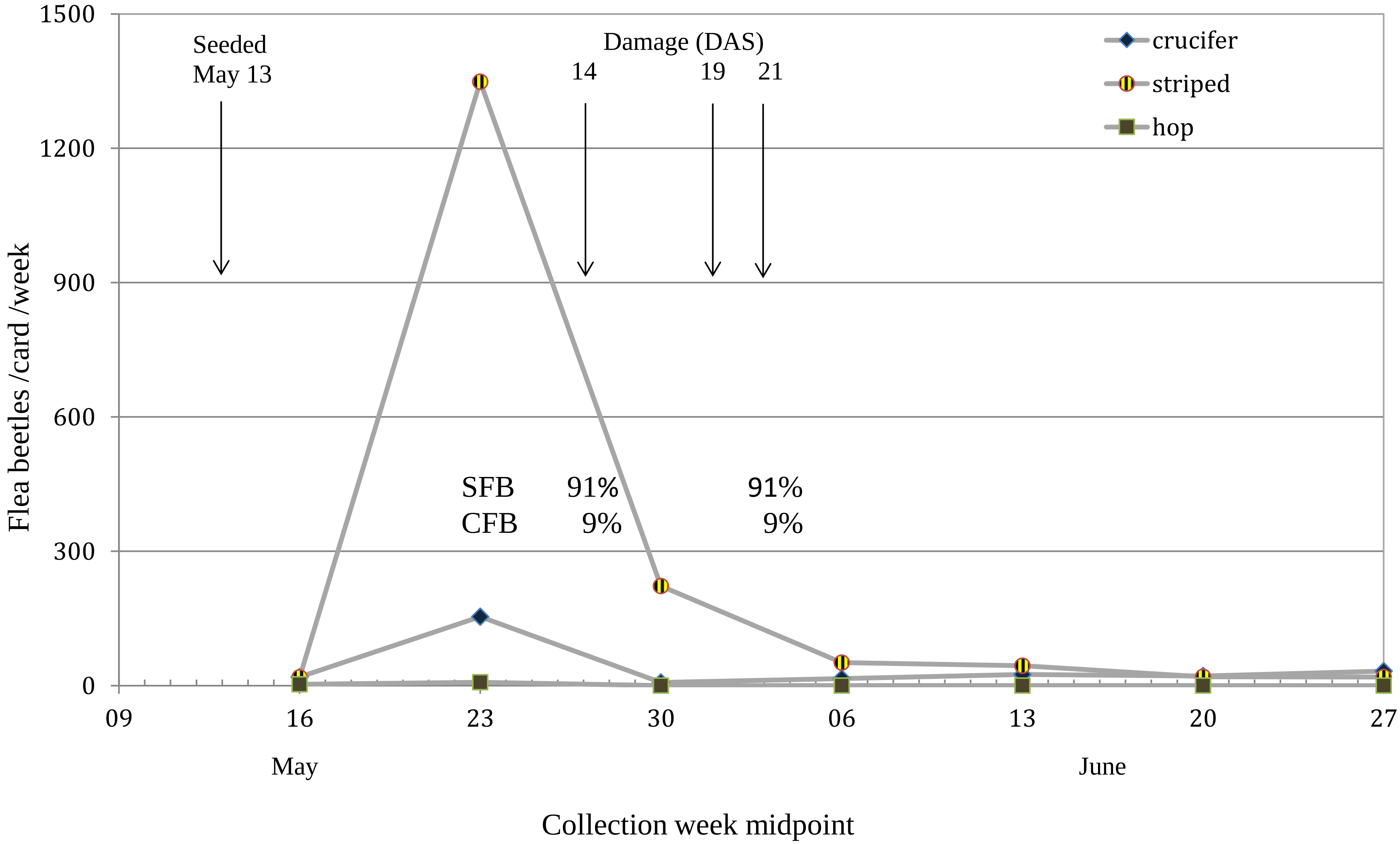


Fig. 71. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of Roundup Ready canola in 2015.

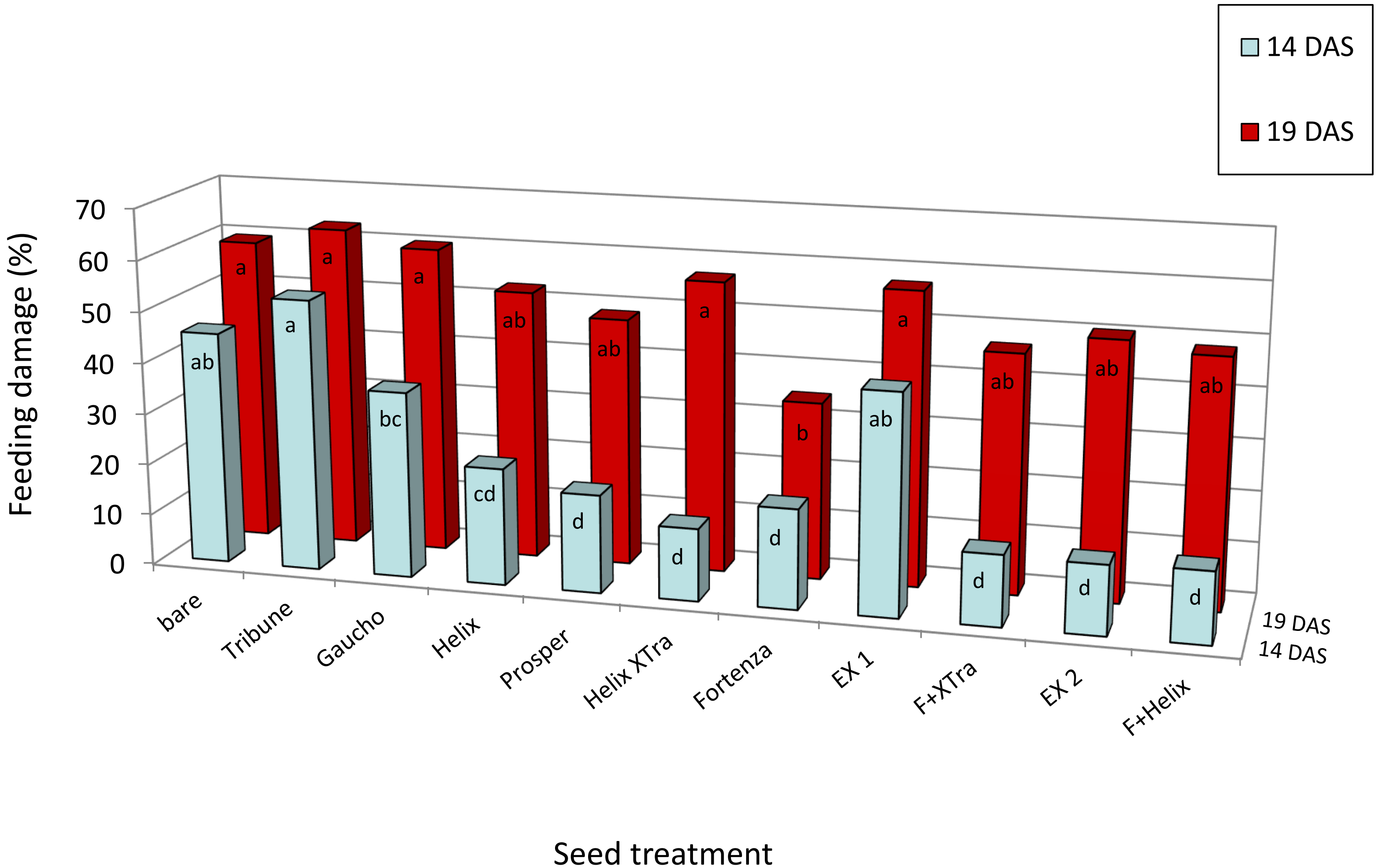


Fig. 72. Effect of seed treatments on flea beetle damage to Roundup Ready canola after 14 and 19 days in 2015.

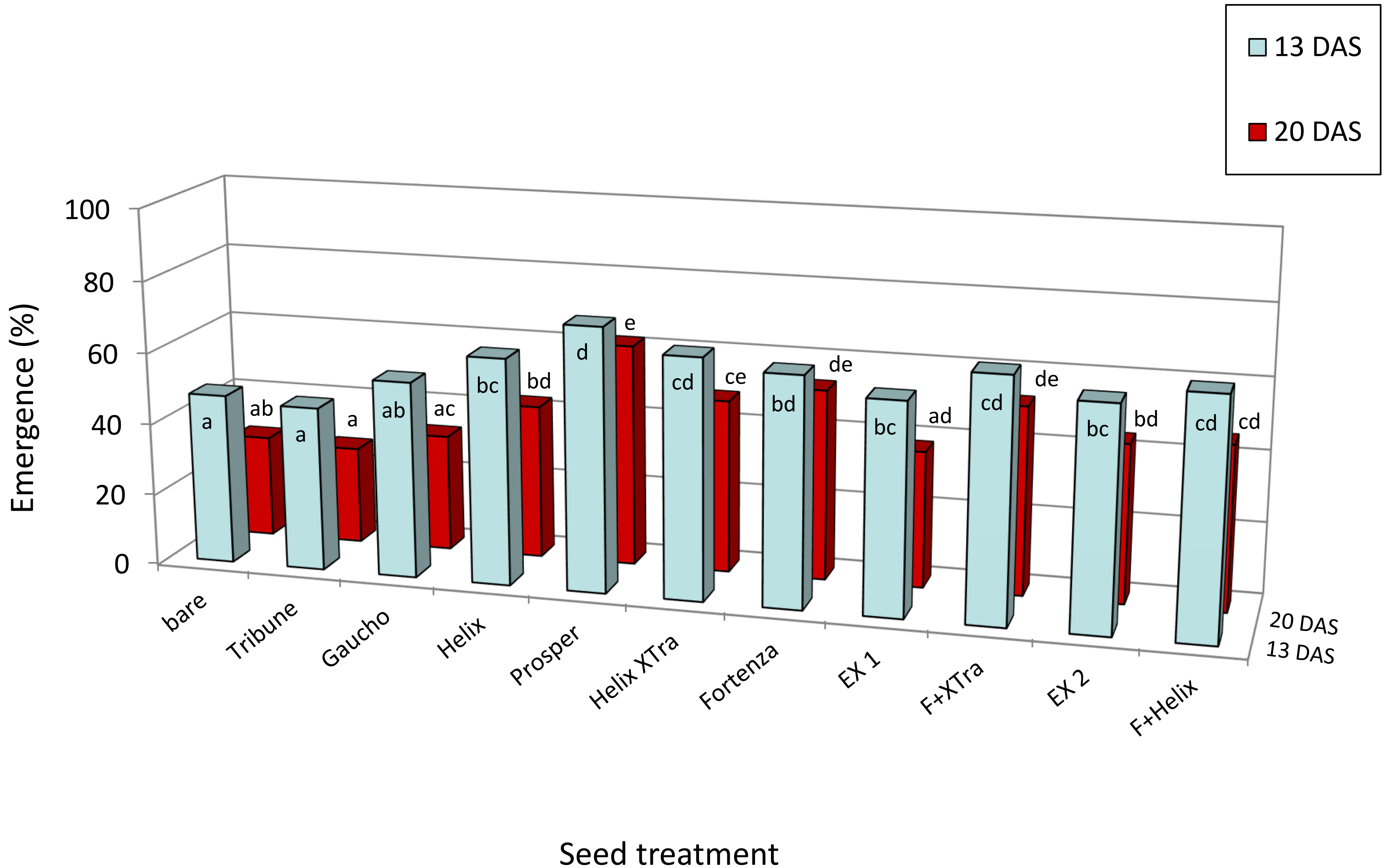


Fig. 73. Effect of seed treatments on emergence of Roundup Ready canola after 13 and 20 days in 2015.

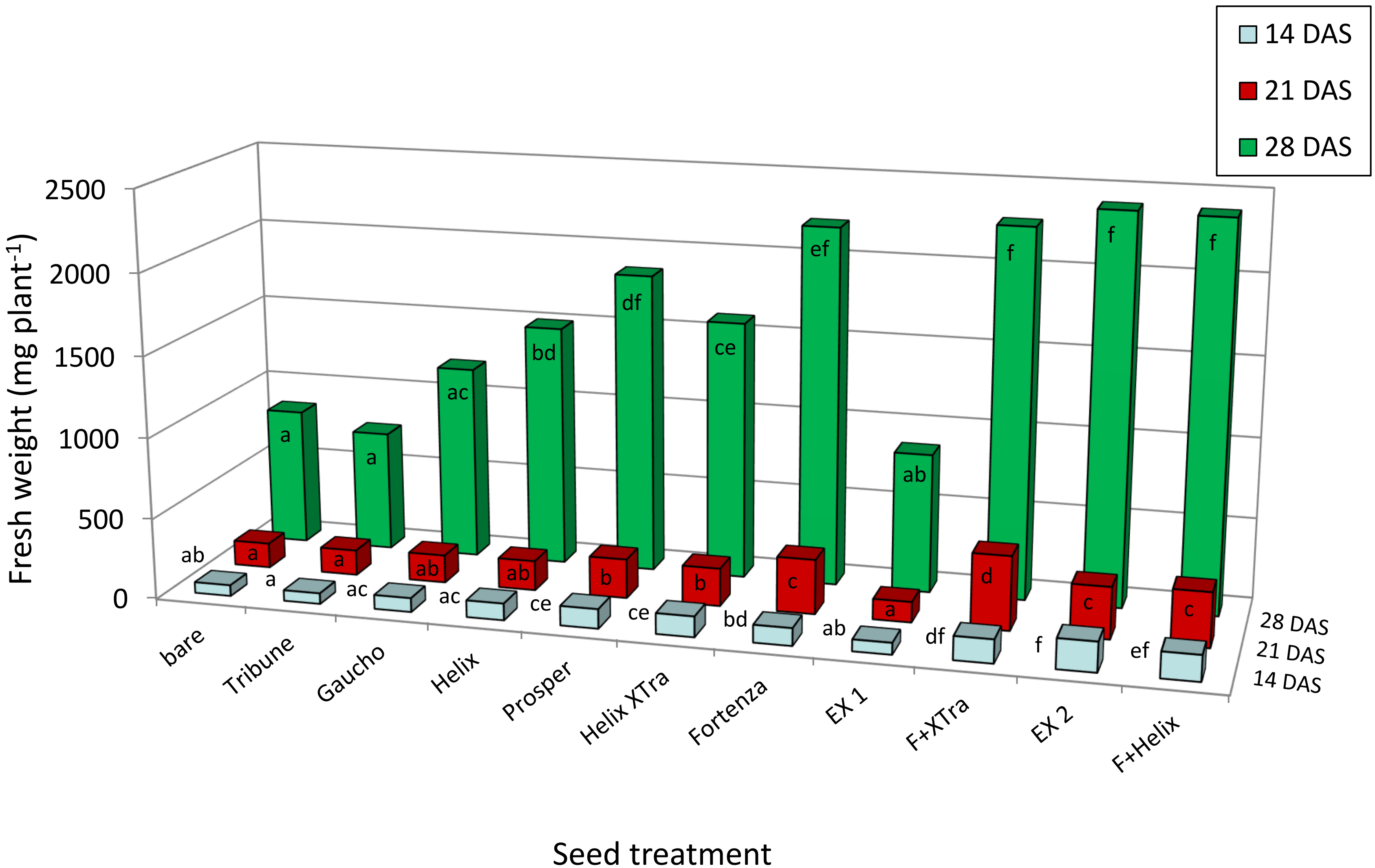


Fig. 74. Effect of seed treatments on fresh weight of Roundup Ready canola after 14, 21 and 28 days in 2015.

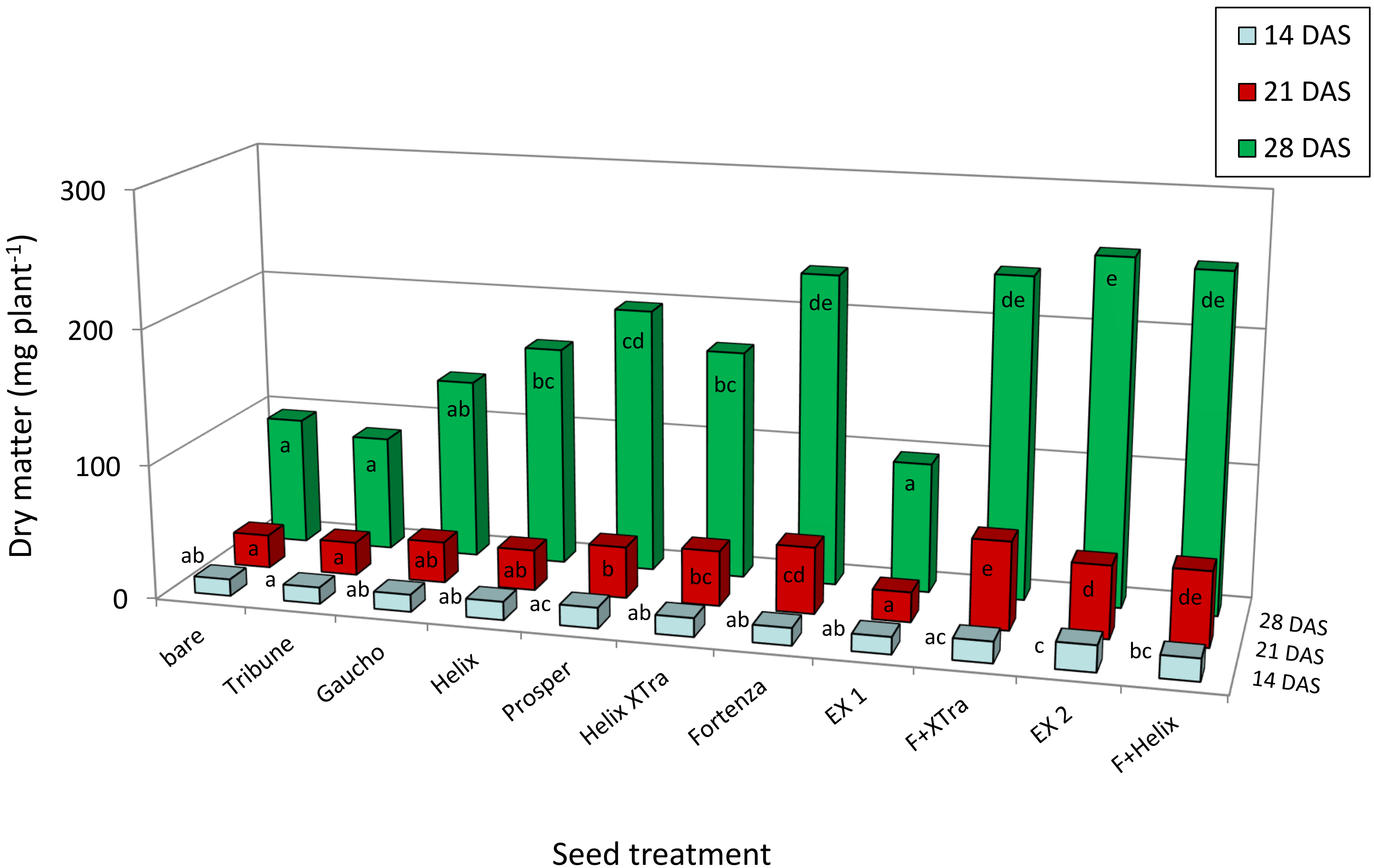


Fig. 75. Effect of seed treatments on dry matter content of Roundup Ready canola after 14, 21 and 28 days in 2015.

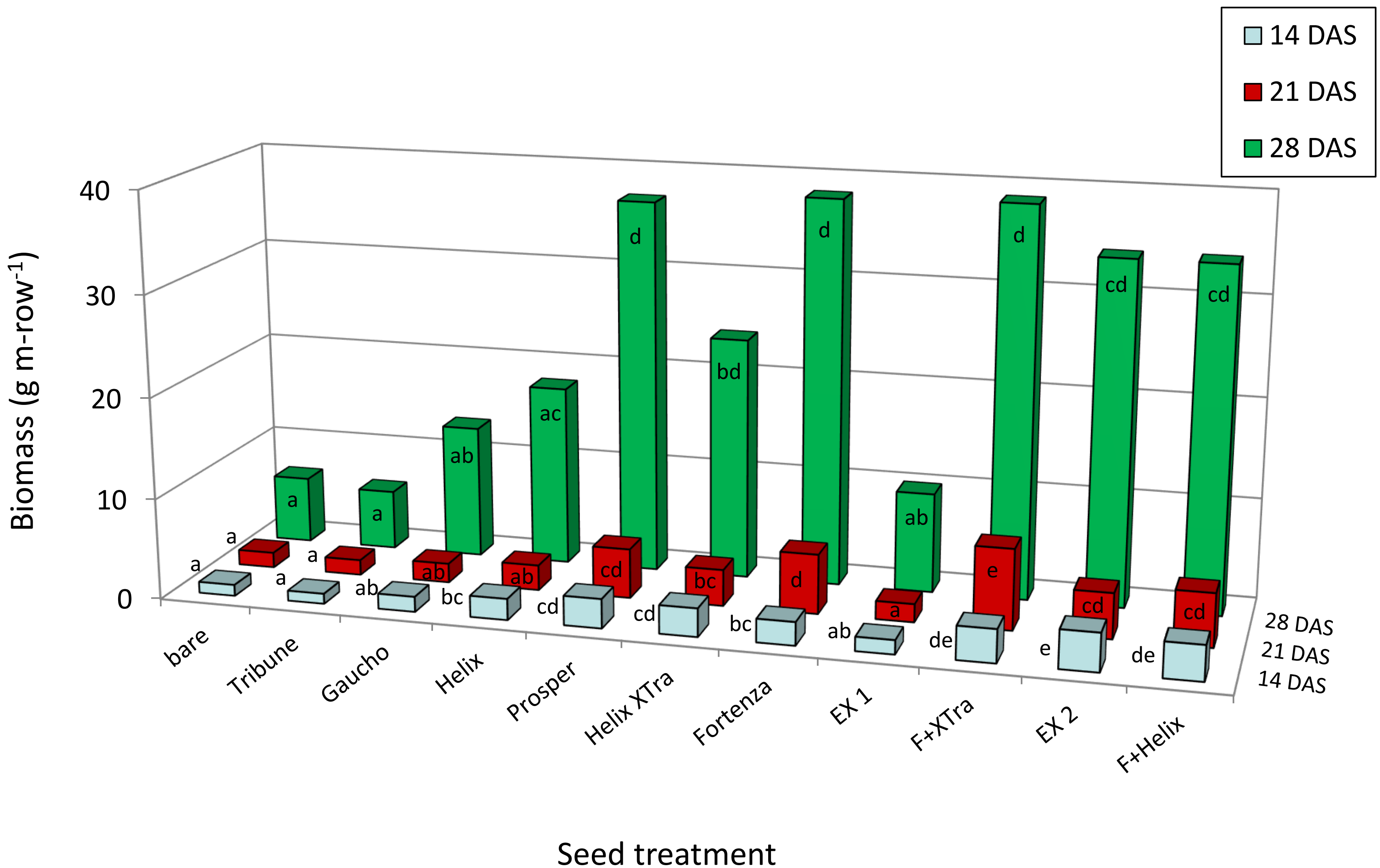


Fig. 76. Effect of seed treatments on biomass of Roundup Ready canola after 14, 21 and 28 days in 2015.

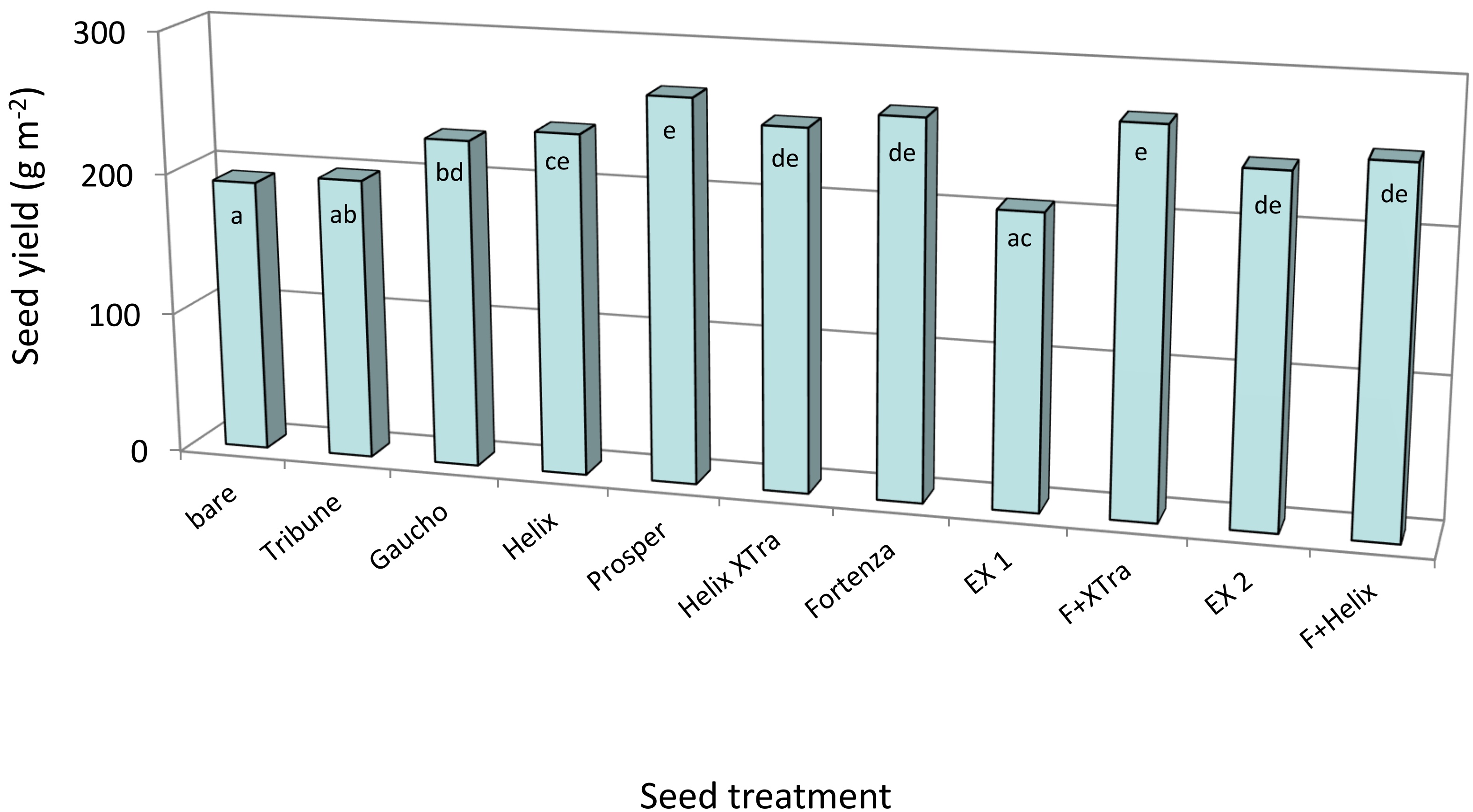


Fig. 77. Effect of seed treatments on seed yield of Roundup Ready canola in 2015.

Table 17. Ranking of seed treatments in field trial on Roundup Ready canola in 2015.

	Protection		Establishment	Biomass	Seed	
Treatment	14 DAS	19 DAS	20 DAS	28 DAS	yield	Overall
bare	9	7	10	10	11	10
Tribune	11	7	11	10	10	11
Gaucho CS FL	8	7	9	8	8	8
Helix	7	2	6	7	7	7
Prosper	1	2	1	1	1	1
Helix XTra	1	7	4	6	3	6
Fortenza (F)	1	1	2	1	3	3
EX 1	9	7	8	8	9	9
F + XTra mix	1	2	2	1	1	2
EX 2	1	2	6	4	3	5
F + Helix mix	1	2	5	4	3	4

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 13.

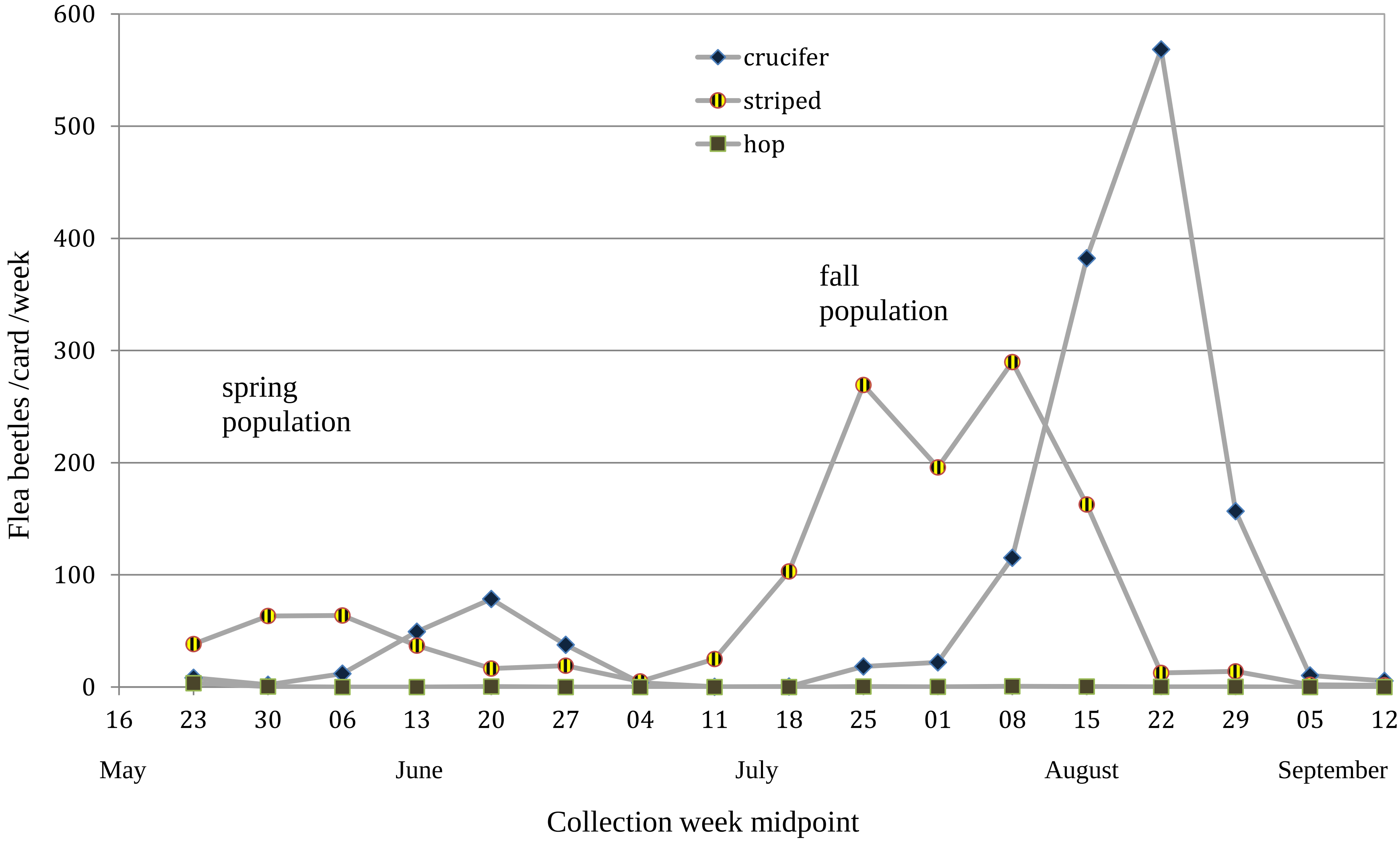


Fig. 78. Numbers of crucifer, striped and hop flea beetles collected on sticky cards in untreated Clearfield canola in 2015.

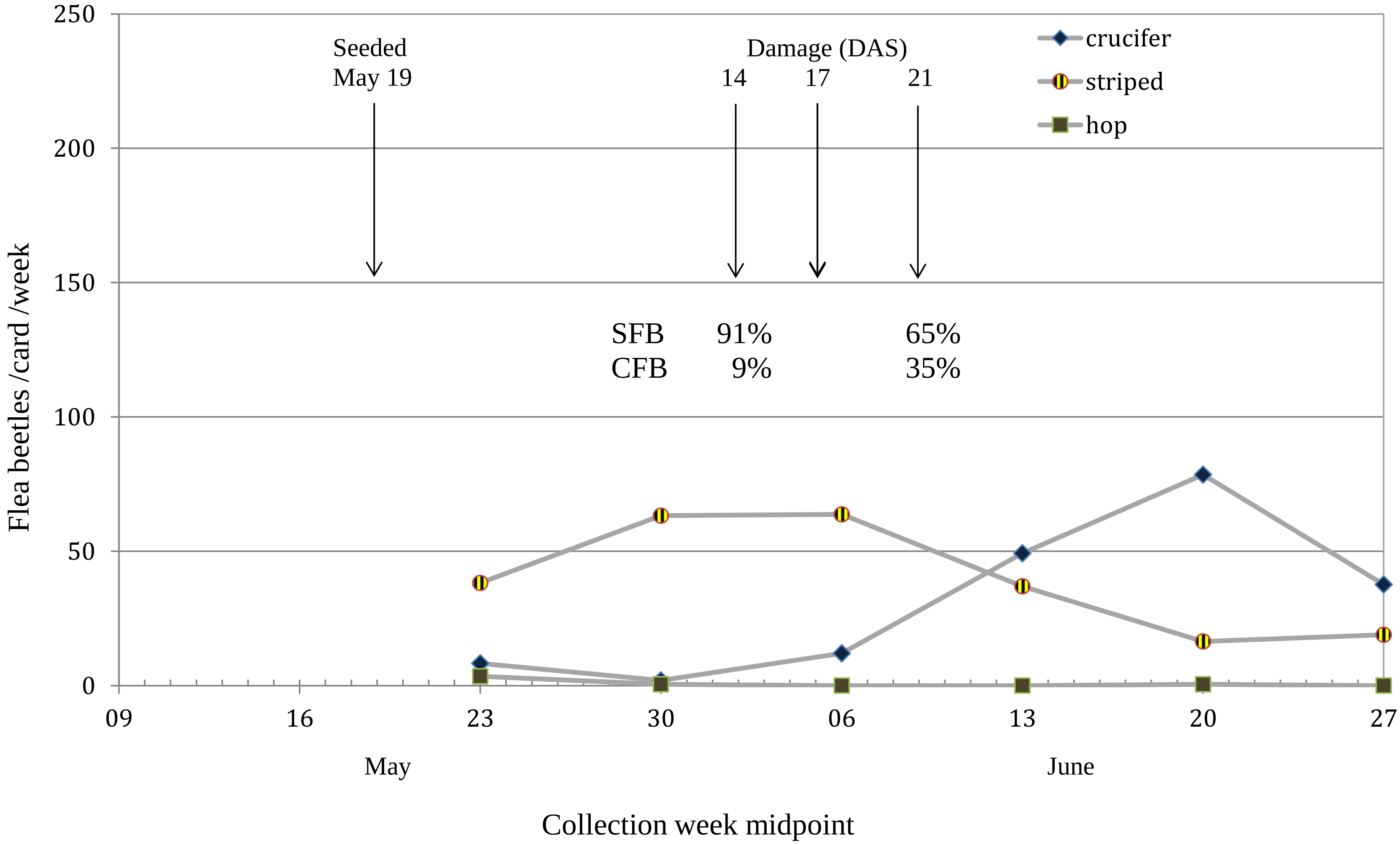


Fig. 79. Numbers of crucifer, striped and hop flea beetles collected on sticky cards during emergence of Clearfield canola in 2015.

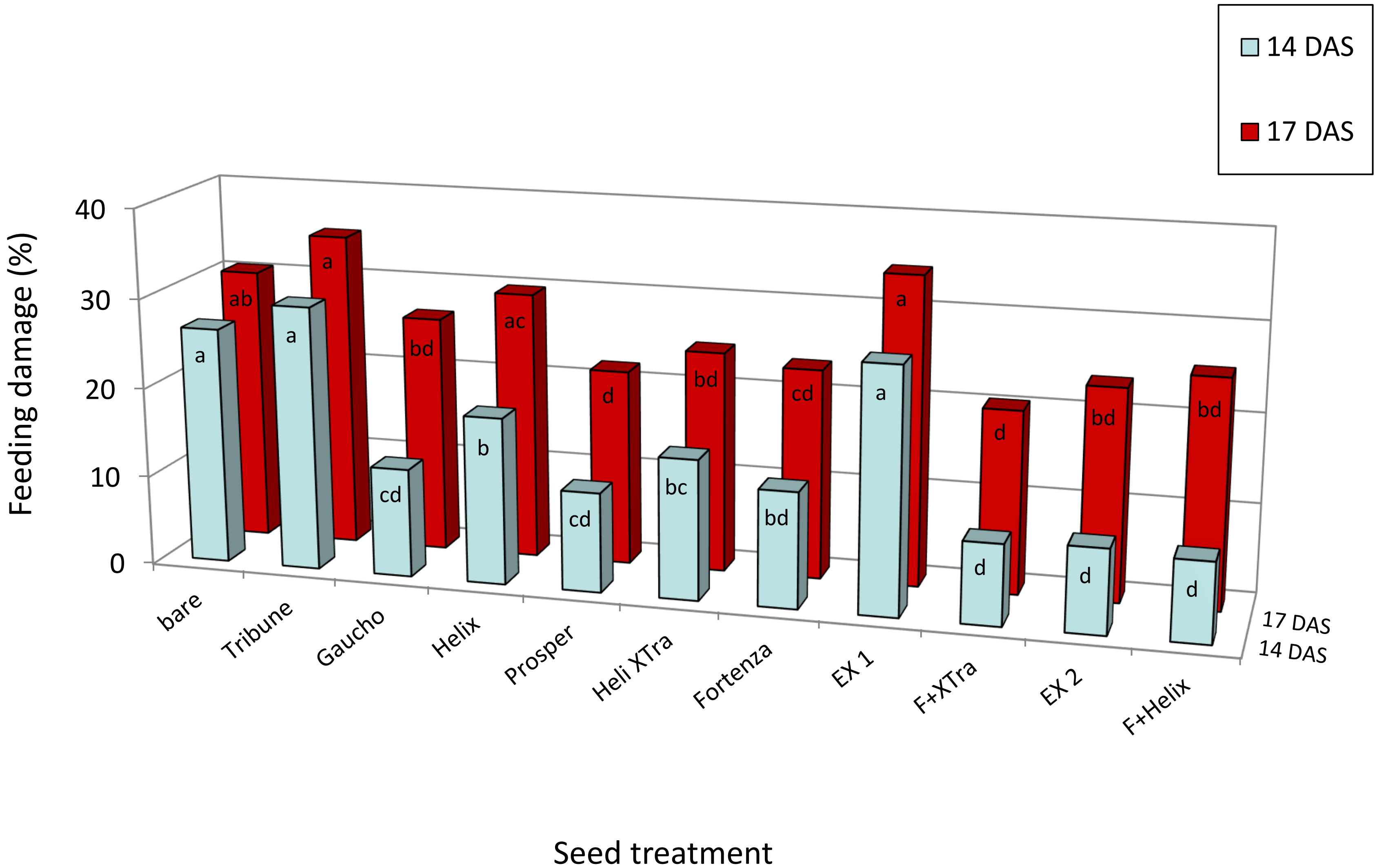


Fig. 80. Effect of seed treatments on flea beetle damage to Clearfield canola after 14 and 17 days in 2015.

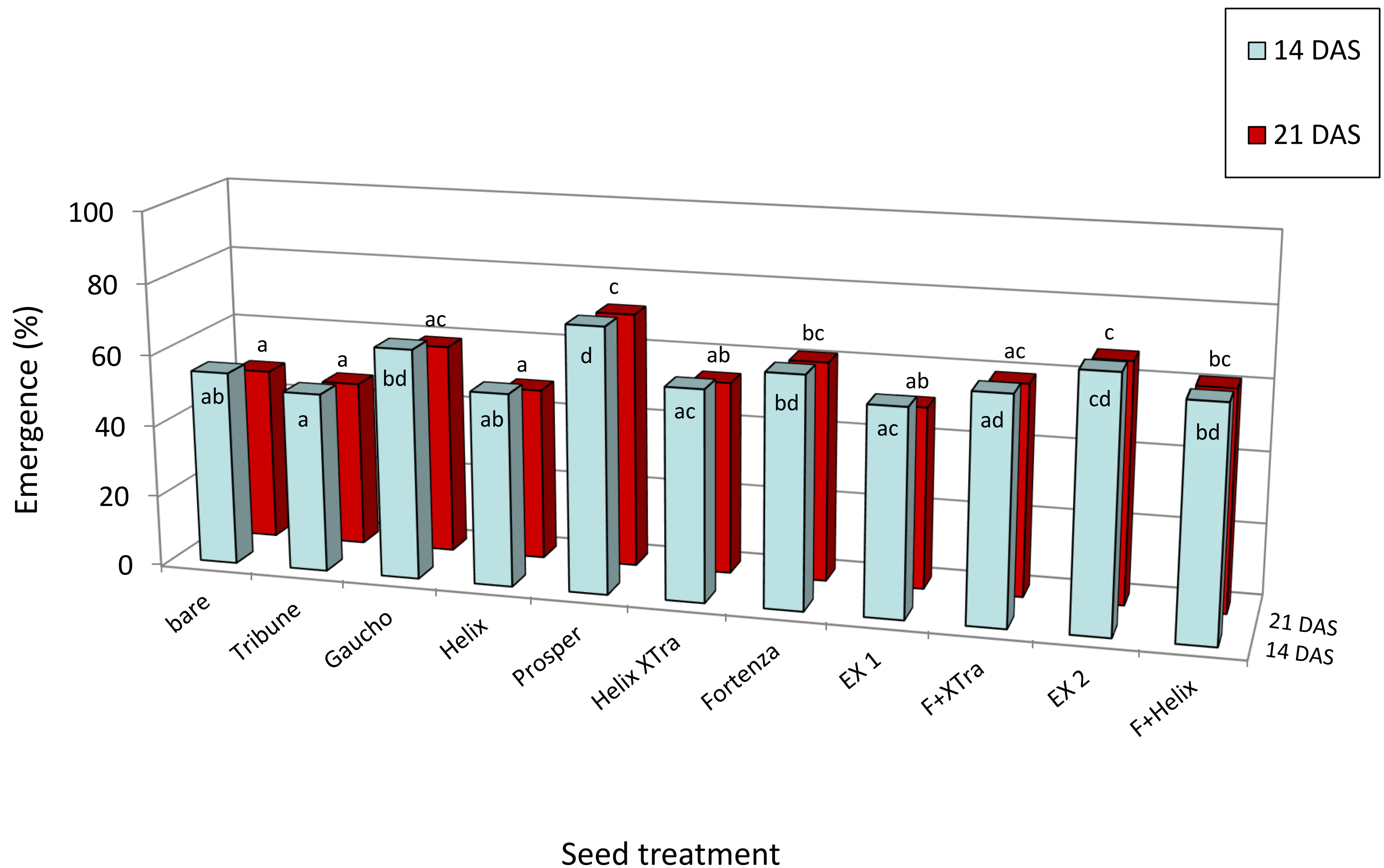


Fig. 81. Effect of seed treatments on emergence of Clearfield canola after 14, 21 and 28 days in 2015.

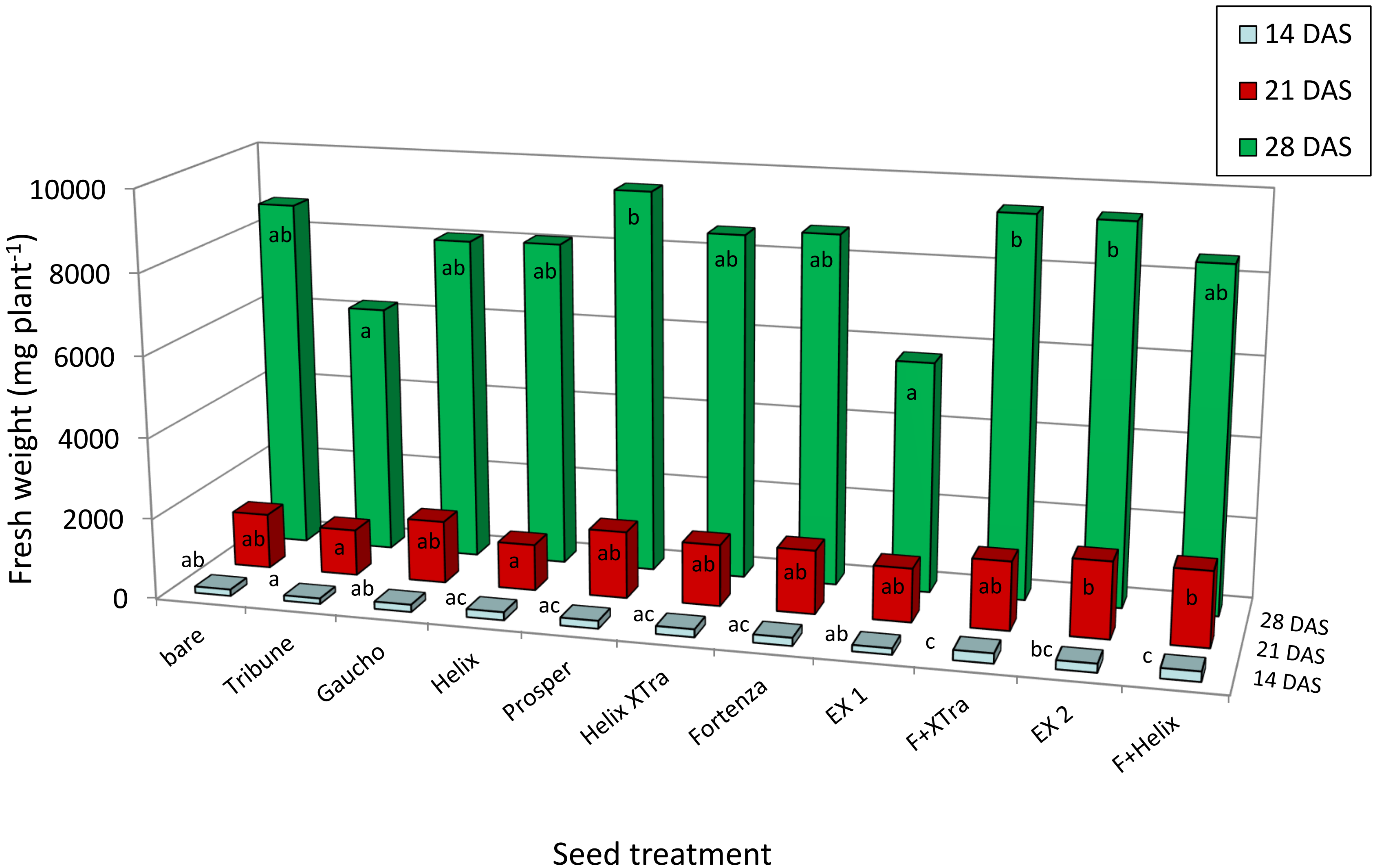


Fig. 82. Effect of seed treatments on fresh weight of Clearfield canola after 14, 21 and 28 days in 2015.

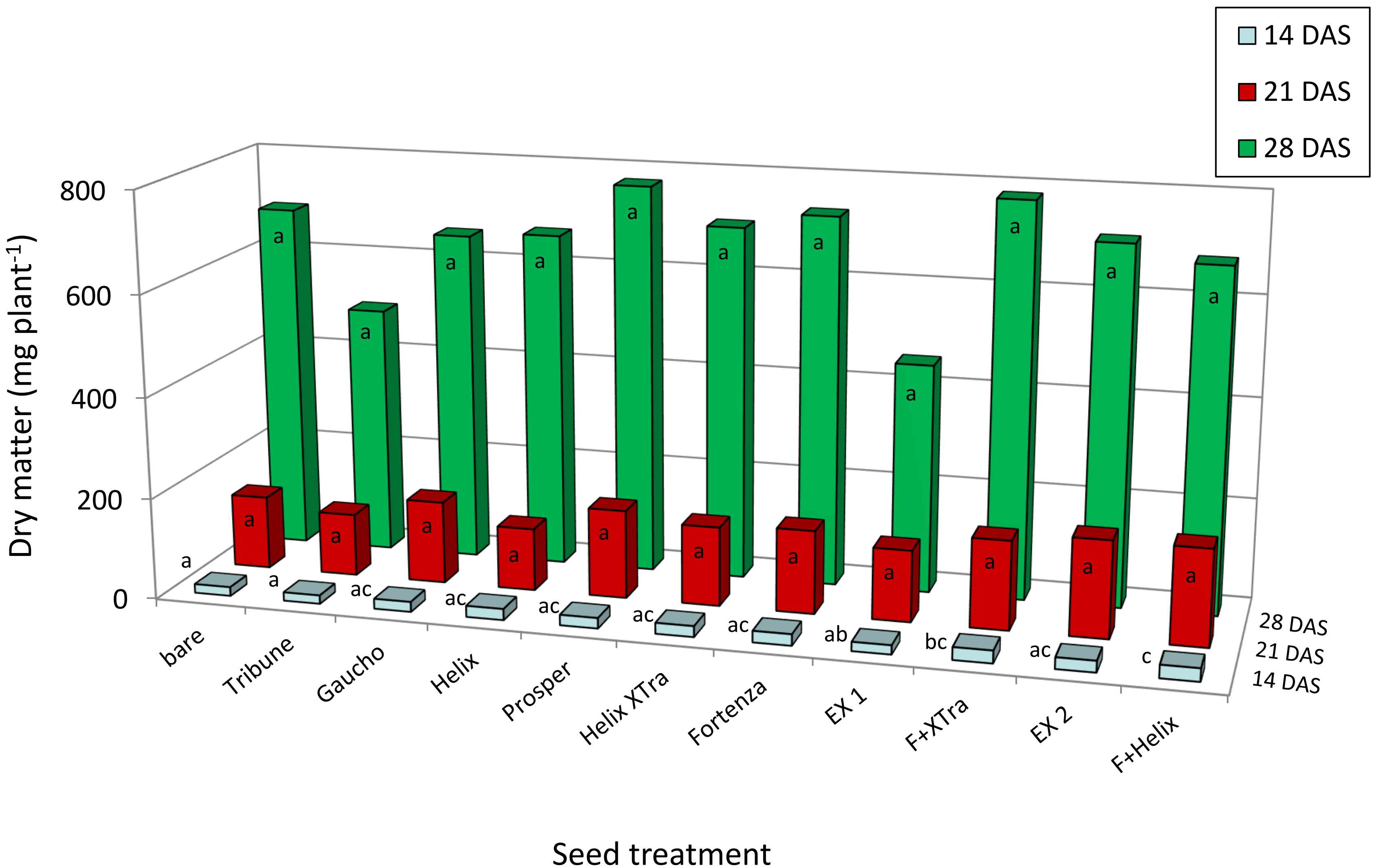


Fig. 83. Effect of seed treatments on dry matter content of Clearfield canola after 14, 21 and 28 days in 2015.

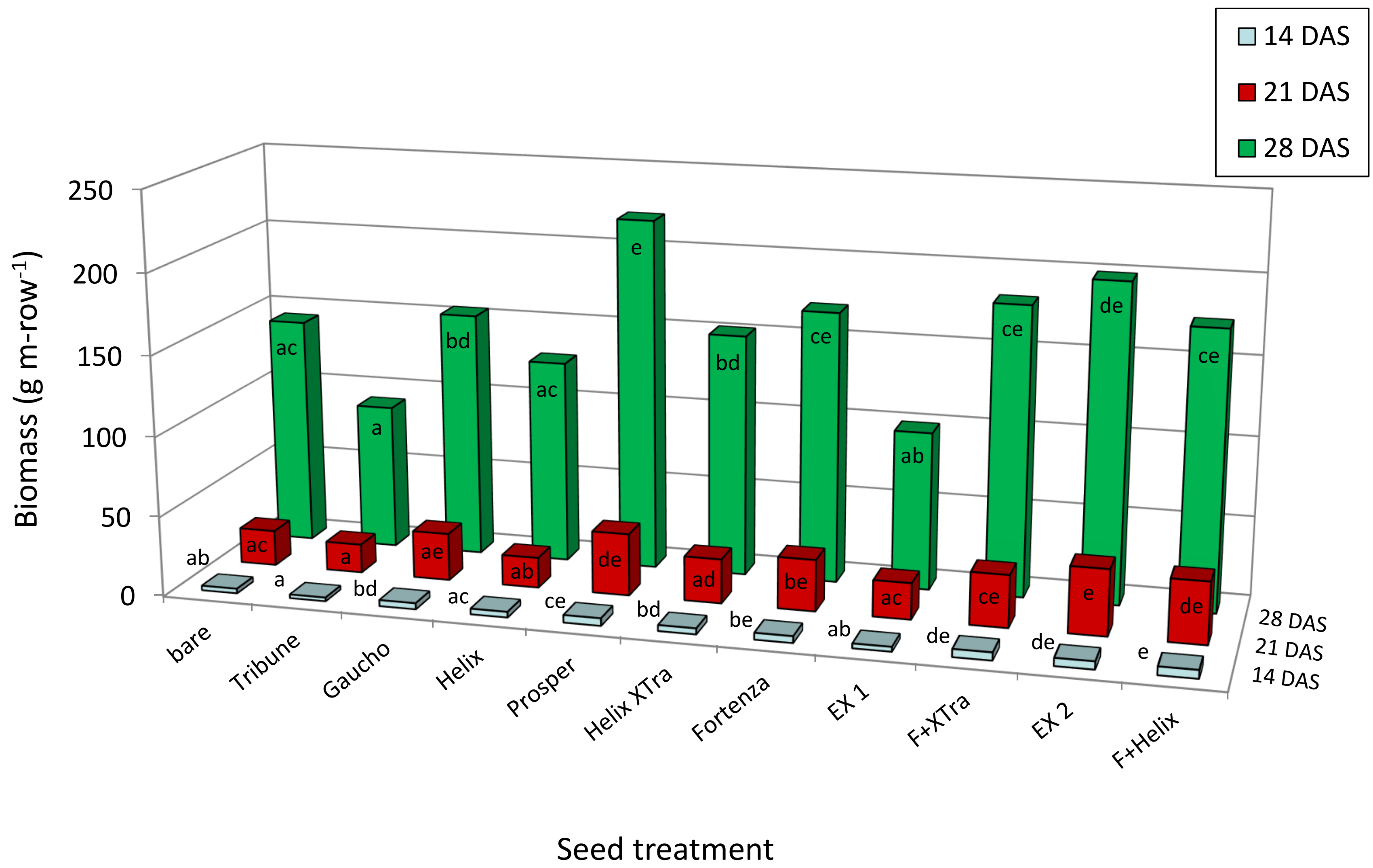


Fig. 84. Effect of seed treatments on biomass of Clearfield canola after 14, 21 and 28 days in 2015.

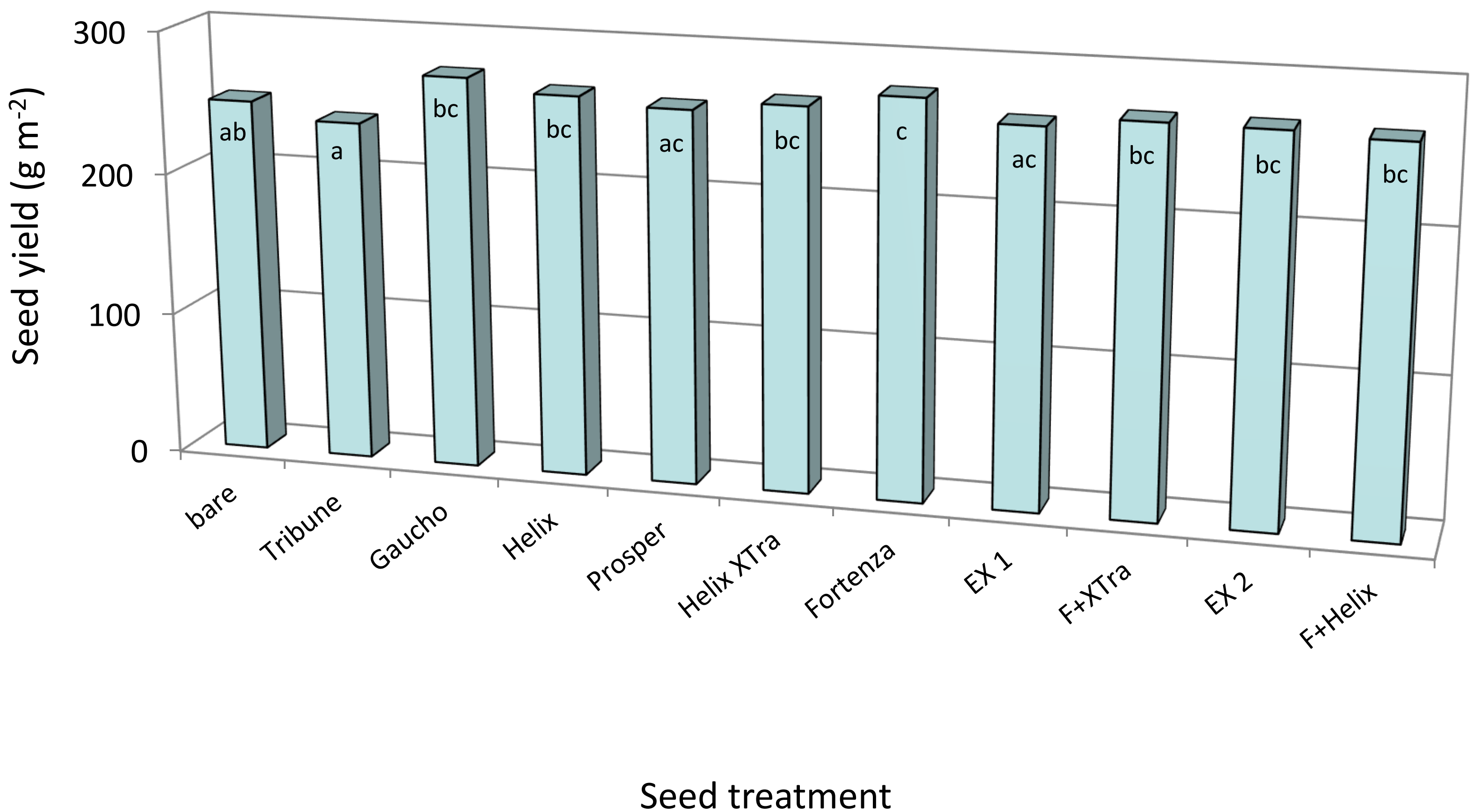


Fig. 85. Effect of seed treatments on seed yield of Clearfield canola in 2015.

Table 18. Ranking of seed treatments in field trial on Clearfield canola in 2015.

Treatment	Protection 14 DAS	Protection 17 DAS	Establishment 21 DAS	Biomass 28 DAS	Seed yield	Overall
bare	9	8	9	8	10	9
Tribune	9	10	9	11	11	11
Gaucho CS FL	4	3	5	6	2	6
Helix	8	8	9	8	2	8
Prosper	4	1	1	1	8	4
Helix XTra	7	3	7	6	2	7
Fortenza (F)	6	3	3	3	1	5
EX 1	9	10	7	10	8	9
F + XTra mix	1	1	5	3	2	2
EX 2	1	3	1	2	2	1
F + Helix mix	1	3	3	3	2	3

Rankings based on Waller comparisons (a = 1, b = 2, c = 3; ab = 1.5, ac = 2) rather than actual values. Test seeded May 19.

Table 19. Correlations between flea beetle damage in seed treatments after 14 days and subsequent performance of different canola types in 2013-2015. [1]

	2013			2014		2015	
Variable	RR canola	CL canola	c. mustard	RR canola	c. mustard	RR canola	CL canola
establishment - 21d	-0.55***	-0.43**	-0.83***	-0.86***	-0.53***	-0.53***	-0.55***
fresh weight - 14d	-0.06NS	-0.27NS	-0.37**	-0.78***	-0.54***	-0.73***	-0.68***
- 21d	-0.38**	-0.06NS	-0.39**	-0.73***	-0.33*	-0.72***	-0.52***
- 28d	-0.30*	-0.09NS	-0.56***	-0.65***	-0.37*	-0.63***	-0.53***
dry matter - 14d	-0.13NS	-0.19NS	-0.09NS	-0.79***	-0.60***	-0.40**	-0.58***
- 21d	-0.42**	-0.06NS	-0.38**	-0.76***	-0.57***	-0.46**	-0.62***
- 28d	-0.37**	-0.06NS	-0.55***	-0.64***	-0.33*	-0.65***	-0.49***
biomass - 14d	-0.17NS	-0.38**	-0.49***	-0.84***	-0.62***	-0.75***	-0.74***
- 21d	-0.48***	-0.23NS	-0.50***	-0.83***	-0.49**	-0.64***	-0.58***
- 28d	-0.42**	-0.21NS	-0.63***	-0.75***	-0.51***	-0.55***	-0.61***

[1] *, **, *** Pearson correlation coefficient (n = 52, 40 and 44 in 2013, 2014 and 2015, respectively) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 20. Pearson correlations between the efficacy of seed treatments against crucifer flea beetles in the lab (% mortality) and performance of the treatments in the field. [1]

	RR canola			CL canola		Canola mustard	
Variable	2013	2014	2015	2013	2015	2013	2014
damage - 14d	-0.83***	-0.83**	-0.90***	-0.81**	-0.74*	-0.79**	-0.54NS
emergence - 21d	0.77**	0.86**	0.73*	0.77**	0.53NS	0.78**	0.70*
fresh weight - 14d	0.23NS	0.91***	0.85**	0.55NS	0.83**	0.67*	0.65*
- 21d	0.85***	0.83**	0.61NS	0.17NS	0.57NS	0.72**	0.63NS
- 28d	0.73**	0.84**	0.75*	0.74**	0.58NS	0.73**	0.39NS
biomass - 14d	0.64*	0.92***	0.91***	0.71**	0.78**	0.72**	0.71*
- 21d	0.88***	0.88***	0.65*	0.53NS	0.58NS	0.77**	0.70*
- 28d	0.80**	0.89***	0.72*	0.79**	0.61NS	0.77**	0.58NS

[1] *, **, *** Pearson coefficient (n = 12, 10 and 10 in 2013, 2014 and 2015, respectively) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 21. Pearson correlations between the efficacy of seed treatments against crucifer flea beetles in the lab (% damage) and performance of the treatments in the field. [1]

Variable	RR canola			CL canola		Canola mustard	
	2013	2014	2015	2013	2015	2013	2014
damage - 14d	0.92***	0.96***	0.85**	0.70*	0.82**	0.92***	0.75**
emergence - 14d	-0.86***	-0.98***	-0.74*	-0.87***	-0.62NS	-0.93***	-0.92***
fresh weight - 14d	-0.14NS	-0.90***	-0.66*	-0.68*	-0.76*	-0.63*	-0.79**
- 21d	-0.73**	-0.89***	-0.50NS	-0.17NS	-0.59NS	-0.76**	-0.65*
- 28d	-0.61*	-0.89***	-0.72*	-0.76**	-0.50NS	-0.83***	-0.57NS
biomass - 14d	-0.60*	-0.93***	-0.74*	-0.87***	-0.79***	-0.76**	-0.89***
- 21d	-0.82**	-0.94***	-0.57NS	-0.58*	-0.61NS	-0.84***	-0.83**
- 28d	-0.73**	-0.93***	-0.70*	-0.83***	-0.60NS	-0.90***	-0.80**

[1] *, **, *** Pearson coefficient (n = 12, 10 and 10 in 2013, 2014 and 2015, respectively) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 22. Pearson correlations between the efficacy of seed treatments against striped flea beetles in the lab (% mortality) and performance of the treatments on in the field. [1]

Variable	RR canola			CL canola		Canola mustard	
	2013	2014	2015	2013	2015	2013	2014
damage - 14d	-0.53NS	-0.55NS	0.55NS	-0.76**	-0.47NS	-0.59*	-0.65*
emergence - 14d	0.56NS	0.65*	0.56NS	0.66*	0.47NS	0.63*	0.68*
fresh weight - 14d	0.32NS	0.65*	0.58NS	0.32NS	0.60NS	0.60*	0.69*
- 21d	0.68*	0.69*	0.53NS	0.15NS	0.56NS	0.44NS	0.84**
- 28d	0.66*	0.90**	0.56NS	0.45NS	0.13NS	0.68*	0.66*
biomass - 14d	0.58*	0.67*	0.63*	0.56NS	0.62NS	0.61*	0.69*
- 21d	0.66*	0.68*	0.59NS	0.47NS	0.53NS	0.48NS	0.81**
- 28d	0.67*	0.83**	0.57NS	0.57NS	0.34NS	0.68*	0.72*

[1] *, **, *** Pearson coefficient (n = 12, 10 and 10 in 2013, 2014 and 2015, respectively) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.

Table 23. Pearson correlations between the efficacy of seed treatments against striped flea beetles in the lab (% damage) and performance of the treatments in the field. [1]

	RR canola			CL canola		Canola mustard	
Variable	2013	2014	2015	2015	2015	2013	2014
damage - 14d	0.60*	0.67*	0.72*	0.61*	0.69*	0.41NS	0.71*
emergence - 14d	-0.66*	-0.75*	-0.67*	-0.51NS	-0.58NS	-0.54NS	-0.77**
fresh weight - 14d	0.12NS	-0.76**	-0.63NS	-0.45NS	-0.65*	-0.67*	-0.83**
- 21d	0.56NS	-0.90***	-0.42NS	-0.46NS	-0.57NS	-0.76**	-0.83*
- 28d	-0.17NS	-0.83**	-0.60NS	-0.59**	-0.27NS	-0.38NS	-0.56NS
biomass - 14d	-0.29NS	-0.77**	-0.70*	-0.46NS	-0.70*	-0.71***	-0.82**
- 21d	-0.63*	-0.85**	-0.51NS	-0.58*	-0.59NS	-0.72**	-0.82**
- 28d	-0.31NS	-0.81**	-0.61NS	-0.61*	-0.47NS	-0.46NS	-0.71*

[1] *, **, *** Pearson coefficient (n = 12, 10 and 10 in 2013, 2014 and 2015, respectively) significant at P = 0.05, 0.01 and 0.001, respectively. NS = not significant.