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PLANT PROTECTION - Article

Growth, phenology, and seed viability between glyphosate-resistant and glyphosate-susceptible hairy fleabane

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ABSTRACT: Glyphosate is the herbicide most used worldwide. In cropping systems that rely on repeated applications of glyphosate or cultivate genetically modified soyabean crop, there are numerous cases of glyphosate resistant weeds, including *Conyza bonariensis*. Differences among competitive ability of *Conyza* spp. have been found. However, little information is available on the fitness costs related to glyphosate resistance in *Conyza bonariensis*. We evaluated growth, phenology, and seed viability of glyphosate-resistant (GR) and glyphosate-susceptible (GS) *Conyza bonariensis* from Brazil, in 2012 (fall/winter) and 2013 (spring/summer). When grown alone, in pots, *C. bonariensis* GR biotype developed more rapidly than the GS biotype, as evidenced by their earlier bolting, flowering, and seed set. In 2012, GR biotype showed 221.9 cm of plant height compared to 181.1 cm from GS, at the flowering time. In both years, the seed production per plant was superior for GR biotype, showing germination higher than 80% against 66.5% from the GS biotype. Thus, *C. bonariensis* GR biotype confirmed no fitness penalty also showing characteristics that allow us to infer in superior competitive with the absence of the herbicide. It is important to point out that the biotypes evaluated here have different genetic background and the differences between them may not be fully attributed to the resistance to glyphosate. However, the GR biotype can persist in the environment and outcompete with GS biotypes regardless of further glyphosate selection of pressure.

KEY WORDS: *Conyza bonariensis*, plant height, dry weight, leaf area, seed set.

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INTRODUCTION

Glyphosate is the herbicide most used worldwide. In Brazil, since 1998, with the genetically modified soyabean (*Glycine max* (L.) Merrill) tolerant to the herbicide being allowed, glyphosate has been used repeatedly causing pressure of selection. *Conyza* b*onariensis* ([L.] Cronquist) is an important weed reported as resistant to glyphosate in Brazil (Moreira et al. 2007; Vargas et al. 2007; Lamego and Vidal 2008).

C. bonariensis belongs to the Asteraceae family and is native of South America, being widely distributed in south-central Brazil (Kissmann 2007). In this country, *Conyza canadensis* (L.) Cronquist (Lamego and Vidal 2008) and *Conyza sumatrensis* (Retz.) E. Walker (Santos et al. 2014) are also found, both resistant to glyphosate. The high adaptability to the main production system used (no tillage) as well as its evolution as resistant to glyphosate, made *C. bonariensis* a major weed in crop systems in Brazil. Thus, farmers are forced to use alternative herbicides, increasing their costs of production. Otherwise, they have to control the weed pulling it by hand.

Herbicide resistance is defined by Food and Agriculture Organization (FAO) as a natural ability of a biotype to survive the chemical application for which the original population was susceptible (LeBaron and Gressel 1982). Fitness is a single value of relative evolutionary success that combines both survival and reproduction and refers to the relative success with which a particular genotype transmits its genes to the next generation (Silvertown and Charlesworth 2001). Some studies have shown fitness costs associated with herbicide resistance in weeds (Moreira et al. 2010). However, others have shown no effect (Westhoven et al. 2008; Travlos and Chachalis 2013). Difference among competitive ability have been found in C. canadensis glyphosate resistant (GR) biotype with high early vigour compared to glyphosate-susceptible (GS) biotypes (Grantz et al. 2008; Shrestha et al. 2007). In another study, although the GR biotype had lower shoot dry mass than the GS biotype when grown alone, in mixed populations of competition, the GR weed were taller and accumulated more dry mass than the GS weeds (Shrestha et al. 2010). Alcorta et al. (2011) observed a delayed phenology in plants resistant to glyphosate.

To develop strategies for management of herbicide-resistant weeds, the knowledge of population dynamic is required. For that herbicide-resistant biotypes which show fitness penalty, it is possible to imagine that in the absence of the herbicide, biotypes will slowly disappear from the population due to reduced competitive ability (Anderson et al. 1996). *Lolium rigidum* Gaud. GR and GS biotypes showed differences in the accumulation of dry weight and seed production, where the GS biotype presented superior performance compared to the GR biotype (Pedersen et al. 2007). The possibility of resistant biotypes present no fitness costs and superior abilities when compared to susceptible, is a concern regarding weeds resistance to herbicides, which results in a greater potential for competition and invasiveness (Anderson et al. 1996). However, studies on fitness costs or benefits related to glyphosate resistance in *C. bonariensis* are rare or incomplete. In the absence of the herbicide, are GR biotypes capable to produce the same seed set of GS biotypes? Are these seeds viable? Is the shoot and root mass of GR biotype the same as GS one? How long is the time to flowering between GR and GS biotypes? These findings may have ecological significance to the population dynamics and may help to understand the behavior of GR biotypes. The physiological characteristics of resistant and susceptible biotypes become crucial to understand and define the competitive ability of a species and may therefore help in the development and use of management methods and prevention of herbicide resistance (Schaedler et al. 2013).

We test the hypotheses that: (i) *C. bonariensis* GR biotype has no fitness penalty related to herbicide resistance, growing faster and taller than GS biotype, with more total biomass and number of leaves; (ii) GR biotype produces earlier and superior seed set with seeds more fecund than GS biotype, which will demand urgent strategies for its management avoiding yield losses and the dominance of the field areas.

MATERIAL AND METHODS

Growth, phenological and seed development

Seeds from 2 previously characterized *C. bonariensis* biotypes from Jaboticaba (lat 27°40′30.18″S; long 53°17′51.12″O) and Frederico Westphalen (lat 27°23′46.31″S; long 53°25′39.50″O), Rio Grande do Sul State, Brazil, were used to determine the differences in growth, phenology and seeds development of GR and GS biotypes, respectively. The methodology adopted was based on Shrestha et al. (2010).

The study was divided into 2 experiments conducted at the greenhouse of the Department of Agricultural and Environmental Sciences (DCAA), Federal University of Santa Maria (UFSM). The first experiment (Experiment 1) was conducted from May to December, in 2012 and the second experiment (Experiment 2) from October to January, 2012/2013.

The GS and GR seeds were soaked into water for 24 h to stimulate germination and then sown into 50 mL plastic cups filled with a commercial soil mixture (TecnoMax®). After the emergence of the first true leaves, seedlings were transplanted into plastic pots of 6 L, also filled with the same substrate. It was remained one plant per pot. Plants were grown in pots to reduce the potential for soil variables affecting the study. The plants were hand watered regularly, and no supplemental fertilizer was added during the experiment. The average temperature during the conduction period of the experiments were 21.05:16.61 °C day:night for Experiment 1 and 25.20:19.82 °C day:night for Experiment 2.

The experiments were arranged as a completely randomized design with the treatments consisted of a factorial. The factor A corresponded to GS and GR biotypes of *C. bonariensis*; factor B, the period in weeks in which the assessments were conducted. It was established that the weekly assessments in both experiments would be conducted until blooming, to unsure harvestingg plants at the same phenological stage. The assessments were performed until 17 weeks after transplanting (WAT) and at the flowering time for Experiment 1 and until 12 and 13 WAT, for GR and GS respectively, for Experiment 2. Each plant was considered a replicate. There were 4 replications in each experiment.

Plant height measurements (main stem only) were made at weekly intervals after transplanting and on the day of plant harvest. The plants were visually inspected on alternate days for formation of a rosette (more than 20 leaves), bolting (extension of the main stem), first appearance of a floral bud, first appearance of an open flower, and first appearance of a flower with seeds. Initial dates for each event were recorded. The assessments were evaluated weekly from the second WAT for rosette diameter (RD), plant height (PH), chlorophyll index (CI), number of leaves (NL), leaf area (LA), shoot dry weight (SDW), root dry weight (RDW), and total dry weight (TDW).

The determination of CI was carried out with digital chlorophyll ClorofiLOG1300 (Falker 2014), in 5 leaves of the average third leaf of each plant, a total of 20 replicates per biotype in each WAT. The NL was measured manually, considering leaves with a better performance than 2 cm and the value, expressed in leaves·plant^{-1}. The quantification of LA was performed using Liquor-3000C Portable Area Meter, and the results presented in cm^2·plant^{-1}. The sampled material was dried in forced air circulation oven with a temperature of 60 °C to constant weight. After drying, the SDW, RDW and TDW were determined in g·plant^{-1}. Four plants of each biotype were used to evaluate the reproductive stage, being flower buds (FBD), flowering (FD), and seed production (SP) recorded. The plants were considered with at least 15 flower buds (chapters) with a diameter greater than 3 mm, as well as the flowering period was defined when at least 15 chapters had bloomed, according to Shrestha et al. (2010).

Seed harvest

The GR and GS seeds from Experiment 1 and Experiment 2 were harvested and kept in a refrigerator at 7 °C. Seed germination experiments were conducted in February, 2013 at Seed Analyses Laboratory of DCCA, UFSM. Seed weight (100 seeds × 8 replicates) was assessed (Brasil 2009).

Germination test

The germination test was conducted using a completely randomized designed with four replications (4 samples of 100 seeds). Seeds were sown on filter paper rolls moistened by distilled water and incubated at 20 °C with 12-h photoperiod, in a germination chamber. Germinated seeds were counted every day for a period of 2 weeks. The germination velocity index (GVI) was calculated according to Maguire (1962). The first counting of germination (FCG) was realized at 7 days after sown aiming to evaluate the normal development of germination.

Emergence velocity index

Four samples of 25 seeds were sown in plastic flats (20 × 10 × 7 cm) filled with a commercial soil mixture (TecnoMax®) and placed in the greenhouse. Twenty-eight days after sown the shoot, root and total plant lengths were measured in 10 seedlings. The 10 seedlings were collected →

and dried in forced air at 70 °C for 48 h for shoot, root and total dry mass determinations.

Seed viability: cold and aging test

Two experiments were conducted to compare the seed viability of GR and GS *C. bonariensis* seed set grown under controlled conditions. The cold test consisted of 4 replicates of 50 seeds sown in plastic boxes filled with filter paper and moistened with distilled water. The plastic boxes were incubated at 10 °C for 7 days. After that, a germination test was conducted according described earlier. The aging test was conducted in plastic boxes containing a blade with 40 mL of water. The seeds were placed on the surface of a screen positioned above the water depth and kept in an incubator at 42 °C for 36 h. After this period, a germination test was conducted with four replications of 50 seeds per treatment (Brasil 2009).

Statistical analyses

Data were submitted to analysis of variance (ANOVA). The treatment means were compared by applying the Minimum Significant Difference (LSD), to 5% of the experimental error probability.

As the interactions were significant ($p < 0.05$) in both experiments, data for RD, PH, CI, NL, LA, SDW, RDW and TDW were regressed against WAT with the use of a 3 parameter sigmoidal model:

$$Y = a/(1 + \exp(- (x - x0)/b))$$

where: Y is the dependent variable (RD; PH; CI; NL; LA; SDW; RDW; TDW); x represents WAT; a means difference between the maximum and minimum asymptote; b means the slope of the curve, x0 represents WAT when the dependent variable is 50% yield of the maximum asymptote (A).

The sigmoidal model was fit with the use of SigmaPlot version 10.0 (Systat Software Inc 2006).

RESULTS AND DISCUSSION

Growth, phenological and seed development

The GR biotype showed a higher RD than GS biotype at all sampling dates (Figure 1a), since 2 WAT, in 2012. The PH based on the main steam elongation begun to be measured 6 WAT for GR biotype whereas for GS it was 1 week later (Figure 1b). The PH showed that the GR biotype developed

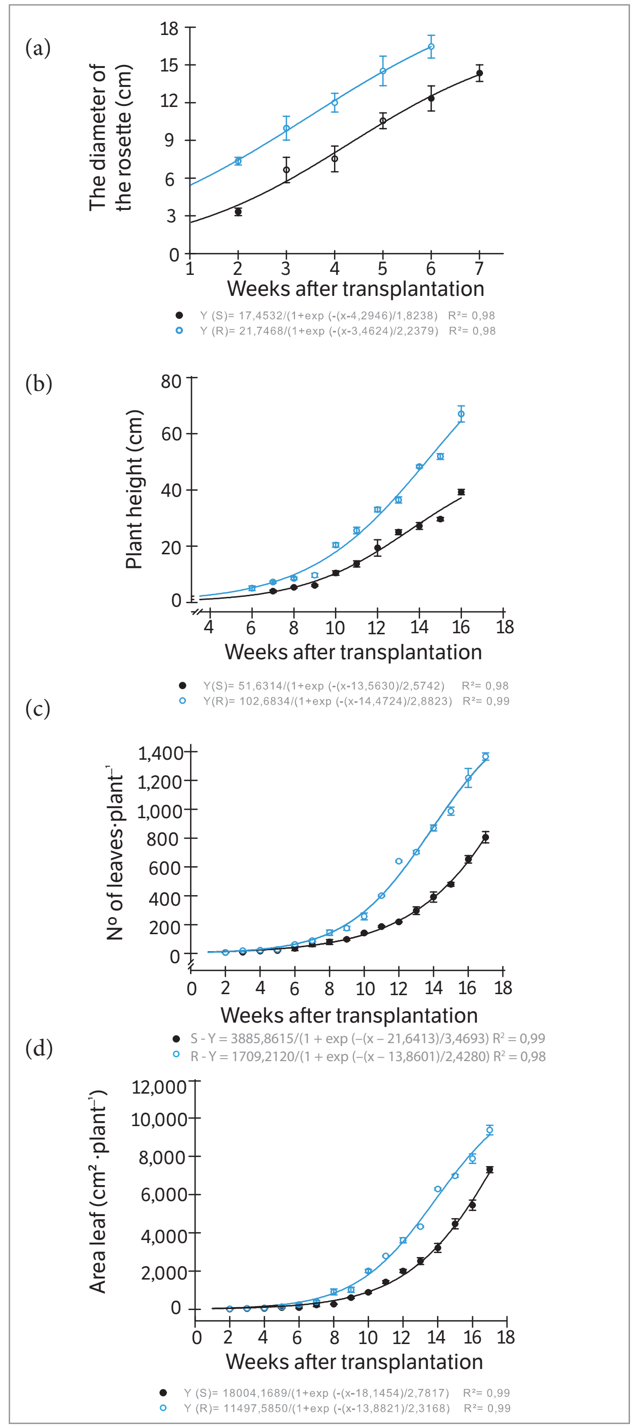

Figure 1. Development of plants biotypes of *Conyza bonariensis*, susceptible (●) and resistant (○) to glyphosate, weeks after transplantation: (a) Diameter of the rosette; (b) Plant height; (c) Number of leaves; (d) Leaf area. Federal University of Santa Maria, Frederico Westphalen Campus (RS), 2012.

more rapidly than the GS biotype, being taller until the last sampling. At 17 WAT, the GR biotype was about 70 cm tall, whereas the GS biotype was only 40 cm. Similar results were observed with GR and GS biotypes of *C. canadensis* by Shrestha et al. (2010).

The high initial capacity of development presented by a plant provides higher potential to occupy the ecological niche in which it operates. For Balbinot Junior et al. (2003) and Rigoli et al. (2009), the occupation of the surrounding space more quickly combined with rapid growth are key factors in establishing the relative competitiveness of plants. Comparing the GR and GS biotypes in two seasons, GR *C. bonariensis* biotype showed superiority with no apparent fitness penalty. In this study, in general, the GR biotype showed superiority for PH, SDW, NL, FA and also a rapidly phenology when compared with the GS biotype, in 2 seasons of experiments. These differences may have an ecological significance when the GR and GS biotypes are growing together. Unfortunately, the biotypes were not evaluated growing in mixed populations which could be a further study.

The results observed in this study are according to Shrestha et al. (2010), which observed in *C. canadensis* biotypes in USA that GS biotype was about 60 cm shorter than the GR biotype. Also, *C. canadensis* plants started to elongate the main stem earlier in the GR than in the GS biotype (Grantz et al. 2008; Shrestha et al. 2010). The growth in height is a feature related to competitiveness, where plants with fast development tend to shade the environment, reducing the availability of light and suppressing the smaller plants (Balbinot Junior et al. 2003). Thus, even in the absence of herbicide application, the GR biotype can have advantageous of establishment and development when compared with the GS biotype.

The NL and LA produced by the biotypes again showed differences, being the GR superior to the GS biotype after 8 WAT (Figures 1c,d). At 17 WAT, the GR biotype showed almost 1400 NL against 800 NL for GS biotype (Figure 1c). Comparing the biotypes, the CI was superior for the GR biotype at all stages of assessment, being 13% superior 17 WAT (Figure 2a). The GR biotype presented an increase in chlorophyll content from the establishment to the 17 WAT, whereas the GS biotype was relatively stable in chlorophyll content from the 7 WAT.

Chlorophylls and carotenoids are the main pigments related to photosynthetic efficiency and, with the establishment of competitive relations the species manifested in the growth and adaptation to different environments (Force et al. 2003). According to Balbinot Junior et al. (2003), higher levels of photosynthetic CI pigments can provide to the biotype, a better use of light and higher net →

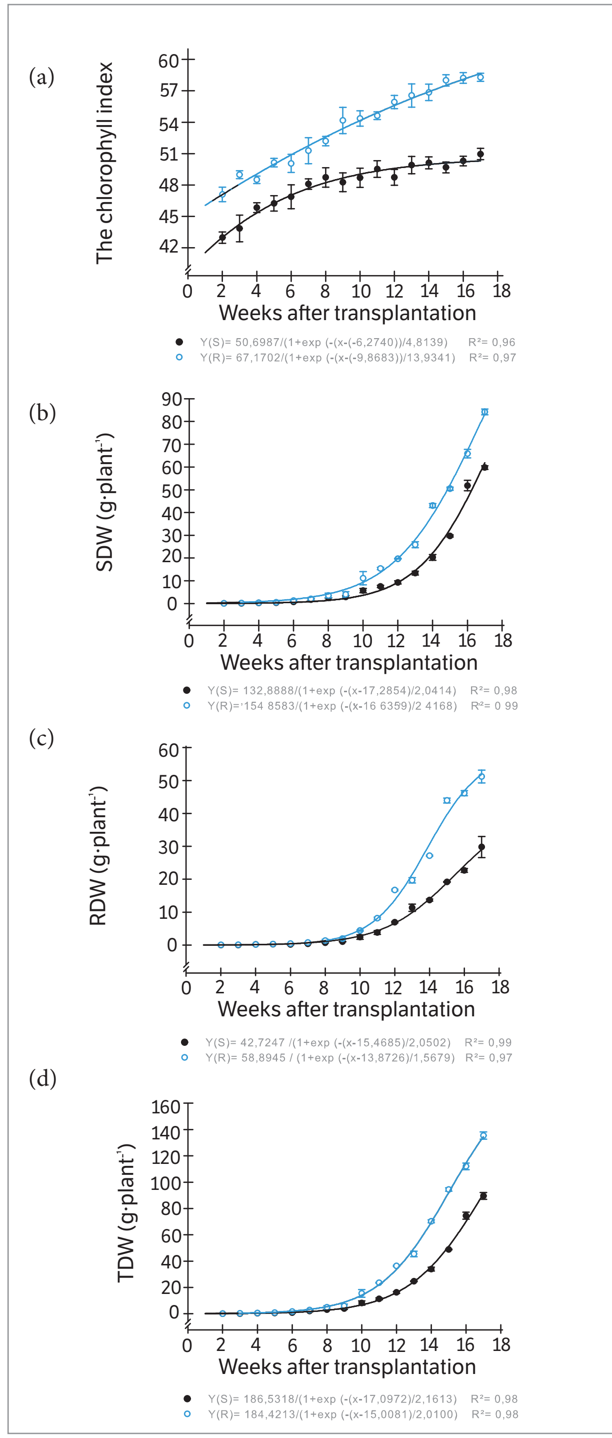

Figure 2. Development of plants biotypes of *Conyza bonariensis*, susceptible (●) and resistant (○) to glyphosate, weeks after transplantation: (a) Chlorophyll index; (b) Shoot dry weight (SDW); (c) Root dry weight (RDW); (d) Total dry weight (TDW). Federal University of Santa Maria, Frederico Westphalen Campus (RS), 2012.

accumulation rate of photoassimilates, including a high-speed growth. Early reduction chlorophyll content is responsible for the premature senescence of leaves and fruits for smaller production in tomato (Schuelter et al. 2008). The highest CI presented by GR biotype implies in a higher use of its light capacity, allowing greater production of photoassimilates and growth of tissues in plants. Similar results were obtained in previous studies (Kaspary et al. 2014). According to the authors, the CI was superior for GR biotype at all stages of plant development: rosette, vegetative and reproductive phase, inferring a higher competitive capacity when compared with GS biotype.

Competitiveness is related to the efficient use of environmental resources on which the plant is located, being the solar radiation an important component in establishing this relationship (Radosevich et al. 2007). A superior NL and LA allow resistant biotype superiority of light interception, resulting in a better general accumulation of photoassimilates and dry mass (Silva et al. 2009).

Therefore, the less NL, LA and CI presented by GS biotype when it reaches the reproductive period, can lead to lower volume of produced seeds and low vigour. Otherwise, the GR biotype presents high levels of CI, which is an important and advantageous feature of competitiveness compared to GS. For higher accumulation of RDW presented by the GR biotype, Silva et al. (2009) point out plants with more developed root system tend to explore greater volume of soil and perform better in case of scarce resources. Further development of the root system favors the absorption of water and nutrients, providing these plants advantages of establishment and development (Carvalho et al. 2008).

The SDW accumulation for GR biotype was approximately 30% more than the GS biotype (Figure 2b). Also the RDW was superior for GR biotype (Figure 2c), being the difference higher, approximately 45%. Thus, GR biotype accumulated more TDW than GS biotype (Figure 2d). However, the differences started to be observed only after 10 WAT, implying the proportional mass accumulation to that period. From the 10th week, the resistant biotype presented high capacity mass accumulation, especially for RDW where the differences compared to the susceptible were higher, deciding in this biotype further exploration capacity of soil resources.

The results observed for dry mass accumulation corroborates with Shrestha et al. (2010) which observed lower mass gain for GS biotype. The same authors reported also the largest capacity of GR plants to accumulate dry mass even in conditions of water deficit. *C. canadensis* plants resistant to glyphosate under stress conditions of ozone also produced about 40% more biomass compared to susceptible biotypes (Grantz et al. 2008). However, studies carried out by Moreira et al. (2010) with GR and GS biotypes of *C. canadensis* and *C. bonariensis* demonstrated lesser amount of dry mass in any resistant biotype, indicating a negative effect on the ability of development of resistant plants. However, in this study as in Shrestha et al. (2010) with *C. canadensis*, there was no fitness penalty for the GR biotype when growing in autumn-winter or spring-summer conditions, but it was seen a further capacity of development in GR biotype compared to the GS.

The time for bolting, forming floral buds, flowering and set seeds was longer to the GS biotype when compared with the GR biotype (Table 1). First floral bud formation was observed 28 days earlier for GR than GS biotype. Seed formation was observed 21 days later for GS biotype. Thus, 17 WAT for Experiment 1 was not enough time to the biotypes start to flower, even to the GR biotype. First flower buds was showed 171 days after the sown for GR biotype or 22.8 WAT. At this time, the NL and the FA for GR biotype were almost twice the number when compared with the GS biotype (Table 1). The differences between biotypes for PH reached 40 cm, being the GS and GR biotypes 181.1 and 221.9 cm tall, respectively. Also, the SDW and TDW, NL and FA were higher for GR biotype (Table 1).

Table 1. Periods in days after sowing necessary to flower buds, flowering, seed, number of leaves, leaf area, seed production, chlorophyll index, plant height, shoot dry weight, root dry weight, and total dry weight, determined to the flowering of *Conyza bonariensis* biotypes, susceptible and resistant to glyphosate. Federal University of Santa Maria, Campus of Frederico Westphalen (RS), 2012.

Biotype	FBD	FD	SD	NL	LA ($cm^2 \cdot plant^{-1}$)	SP	CI	PH (cm)	SDW ($g \cdot plant^{-1}$)	RDW ($g \cdot plant^{-1}$)	TDW ($g \cdot plant^{-1}$)
S	199.2*	216.5*	221.8*	1,755.7*	8,426.2*	366,425.0*	49.4*	181.1*	340.0*	99.0^{ns}	439.1*
R	171	190.5	201.8	3,132.00	13,646.80	878,086.00	60.6	221.9	437.0	111.5	549.1
Mean	185.1	203.5	211.7	2,443.90	11,036.50	622,255.50	54.9	201.5	388.5	105.3	494.1
CV (%)	**4.9**	**5.3**	**5.9**	**5.6**	**6.2**	**13.4**	**5.7**	**6.8**	**6.5**	**10.9**	**6.5**

*Means biotypes in different columns, different by the t-test ($p = 0.05$); ^{ns}No significant ($p \geq 0.05$). FBD = Flower buds; FD = Flowering; SD = Seed; NL = Number of leaves per plant; LA = Leaf area; SP = Seed production per plant; S = Susceptible; R = Resistant; CV = Coefficient of variation; CI = Chlorophyll index; PH = Plant height; SDW = Shoot dry weight; RDW = Root dry weight; TDW = Total dry weight.

In general, growth differences between GR and GS biotypes may affect the persistence and the frequency of resistant biotypes to herbicides, where the reduction of the ecological and reproductive fitness would result in the reduction of their frequency under the absence of pressure selection caused by the herbicide (Travlos and Chachalis 2013). Christoffoleti (2001) point the absence of herbicide application, as faster as the GS plants grow less the GR biotype occupy the ecological niche. However, there is no fitness penalty for GR biotypes, being superiority observed in growth features and seed production. In competition with vines, GR biotype of *C. canadensis* accumulated more dry mass than GS (Alcorta et al. 2011). Thus, there is a predominance of resistant individual occupying the ecological niche, even in the absence of glyphosate.

During the Fall/winter Season (Experiment 1), the development of GS biotype was always delayed when compared to the GR biotype. At the same conditions, the GR biotype when compared to the GS biotype exhibited accelerated phenological development, blooming 28 days earlier. The FB for GR biotype was 38% superior to the GS biotype (Table 1). Also, an estimate of SP by the GR biotype showed 878,086 seeds·plant^{-1} against only 366,425 seeds·plant^{-1} by the GS biotype (Table 1).

From October to January 2013, the cycle of plant development observed for both biotypes was shorter. Probably, because of the highest daylight associated with higher temperatures, common features for the experiment season. The rosette was formed very quickly by GR and GS biotypes, being the data not fit to the model used, thus it was not possible to compare them (unshown data). Again, the GR biotype developed more rapidly than the GS biotype, being taller that the GS until the last sampling of plant height based on the main stem elongation (Figure 3a). However, there was a significant difference between biotypes at 5 WAT, whereas in the Experiment 1 was possible to observe significant differences only from 10 WAT (Figures 1a,3a). The inferior PH from the GS biotype also reflected in its smaller NL and LA (Figures 3b,c).

The high LA along with a high CI can provide to the GR biotype superior ability to intercept and use light, which indicates overall gain of photoassimilates by plant, which contribute to a higher accumulation of SDW, RDW and TDW (Figures 4b,c,d, respectively). The GR biotype of *C. bonariensis* required about only 92.3 days to the first appearance of a FB, and 114.8 days to show flowers with seeds (Table 2). However, the GS biotype required a significantly longer period with 105.5 and 121 days

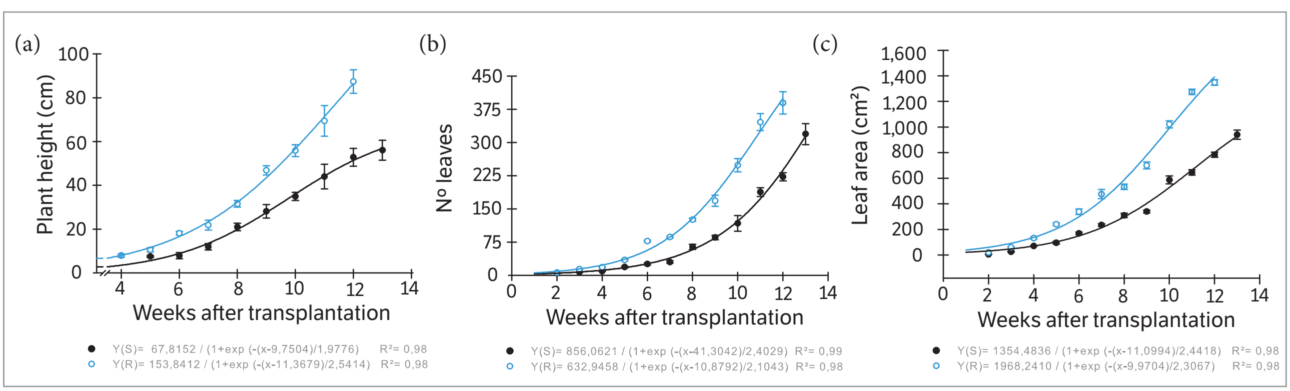

Figure 3. Development of plants biotypes of *Conyza bonariensis*, susceptible (●) and resistant (○) to glyphosate, weeks after transplantation: (a) Plant height; (b) Number of leaves; (c) Leaf area. Federal University of Santa Maria, Frederico Westphalen Campus (RS), 2013.

Table 2. Period in days after sowing necessary to flower buds, flowering, seed, number of leaves, leaf area, seed production, chlorophyll index, plant height, shoot dry weight, root dry weight, and total dry weight, determined to the flowering of *Conyza bonariensis* biotypes, susceptible and resistant to glyphosate. Federal University of Santa Maria, Campus of Frederico Westphalen (RS), 2013.

Biotype	FBD	FD	SD	NL	LA (cm²·plant⁻¹)	SP	CI	PH (cm)	SDW (g·plant⁻¹)	RDW (g·plant⁻¹)	TDW (g·plant⁻¹)
S	105.5*	113.8*	121.0*	517.25*	886.30*	140,971.0*	41.16*	151.25*	52.64*	10.26*	62.80*
R	92.3	107.3	114.8	1,025.25	2,286.60	598,094.2	58.42	189.25	109.33	19.50	128.83
Mean	98.9	110.5	117.9	771.25	1,586.45	369,532.5	49.79	170.25	80.98	14.88	95.86
CV (%)	2.25	3.04	2.16	5.98	10.27	4.91	4.05	6.94	18.05	16.85	16.38

*Means biotypes in different columns, different by the t-test ($p = 0.05$); ns No significant ($p \geq 0.05$). FBD = Flower buds; FD = Flowering; SD = Seed; NL = Number of leaves per plant; LA = Leaf area; SP = Seed production per plant; S = Susceptible; R = Resistant; CV = Coefficient of variation; CI = Chlorophyll index; PH = Plant height; SDW = Shoot dry weight; RDW = Root dry weight; TDW = Total dry weight.

to show floral buds and flowers with seeds, respectively. The seed set for GR biotype was observed 12 WAT whereas the GS biotype needed one week more (Table 2). However, for both biotypes the period was earlier than those of Experiment 1. At the flowering time, the NL, FA, CI and PH for the GR biotype were superior to GS biotype (Table 2). The estimate of SP by the GR biotype was 76% superior the SP of the GS biotype (Table 2). Thus, despite the longer cycle, the GS biotype presented lower performance for all variables evaluated when compared with the GR biotype (Table 2).

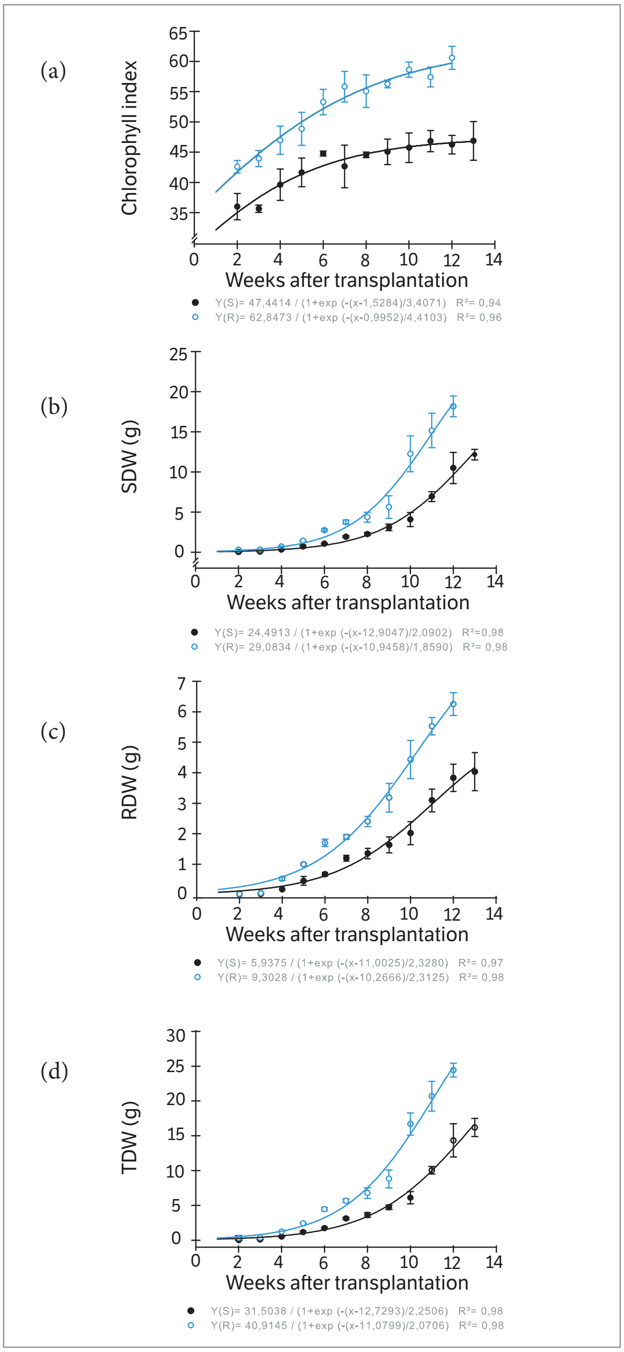

Figure 4. Development of plants biotypes of *Conyza bonariensis*, susceptible (●) and resistant (○) to glyphosate, weeks after transplantation: (a) Chlorophyll index; (b) Shoot dry weight (SDW); (c) Root dry weight (RDW); (d) Total dry weight (TDW). Federal University of Santa Maria, Frederico Westphalen Campus (RS), 2013.

The differences observed during the experiments show that *C. bonariensis* is affected by photoperiod, flowering earlier when the days are longer (December – March). Shrestha et al. (2010) reported about 3 – 4 weeks later for the susceptible biotypes of *C. canadensis* to flower and start seed maturation. Similar behavior was observed at *Chenopodium album* L. plants tolerant to glyphosate, which presented anticipation in 4 to 6 weeks in flowering structures, compared to susceptible plants (Westhoven et al. 2008). The GR biotype capacity to produce seeds in short time provides a higher number of seed set per year, which increases the production of seeds.

Germination Seeds and Seed Viability

Seeds from Experiment 1 and Experiment 2 showed the same pattern of germination (Tables 1, 2). The percentual of germination for GS and GR biotypes from Experiment 1 was 66.5 and 83.75%, respectively, and, from Experiment 2, 58.50 and 86.25%, respectively (Tables 1, 2). According to the aging test and cold test, seeds from GR biotype showed superior quality when compared with the GS biotype. Even under adverse conditions of temperature and humidity, GR seeds showed better germination.

It is important to point out that the biotypes evaluated here have different genetic background. Thus, the differences between them may not be fully attributed to the resistance to glyphosate. However, the importance of this study is to evaluate the growth, phenology and seed production by the biotypes when growing in similar conditions.

CONCLUSION

No apparent fitness penalty for GR biotype is observed, thus it is likely to persist in the environment. Thus, integrated weed management strategies should be adopted as using crop rotation with no glyphosate resistant crop, choosing for soybean cultivars with superior competitive ability and avoiding seed production by C. bonariensis. Also, it is required to understand the population dynamics and potential impacts of the resistant biotype avoiding the evolution of new herbicide resistant biotypes.

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