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Post-fire flowering and fruiting in *Vellozia sincorana*, a caulescent rosette plant endemic to Northeast Brazil

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RESUMO

(Floração e frutificação depois de fogo em *Vellozia sincorana*, planta caulescente de roseta endêmica do Nordeste do Brasil). *Vellozia sincorana* L.B. Sm. & Ayensu é uma espécie endêmica dos campos rupestres ameaçada pela coleta de seus ramos resinosos destinados a acender fogões. A floração em massa de *V. sincorana* observada depois de incêndio em outubro de 1999 suscitou as seguintes perguntas: O fogo afeta a floração e frutificação de *V. sincorana*? A altura dos indivíduos é correlacionada com a produção de flores e frutos? Um incêndio em 08 de novembro de 2008 foi oportuno para explorar essas questões. Foram monitoradas populações de *V. sincorana* em duas áreas de campos rupestres em morros no Parque Nacional da Chapada Diamantina (12º31'S - 41º29'W; 12º36'S - 41º28'W), uma acometida pelo incêndio de novembro de 2008 e a outra não queimada desde 1999. Em ambas as áreas, 25 indivíduos foram sorteados e monitorados. Os números de flores e frutos foram contados e as alturas das plantas foram medidas em nove amostragens realizadas entre 2008 e 2010. Correlação de Spearman e regressão linear foram utilizadas para avaliar a relação entre altura dos indivíduos e a fenologia. Floração e frutificação ocorreram apenas na população queimada a menos tempo, cerca de 40 dias depois do fogo e em 24 dos 25 indivíduos monitorados (96%). A quantidade de flores e/ou frutos foi positivamente e significativamente correlacionada com a altura das plantas. A abundante floração depois do incêndio é um indicativo do fogo como fator que dispara essa fase fenológica. Estimativa da idade de indivíduos altos e eventos de floração podem ser utilizados para estimar a frequência do fogo em áreas de populações de *V. sincorana*, contribuindo para o conhecimento da ecologia do fogo e para conservação biológica e manejo do fogo nos campos rupestres.

Palavras-chave: campos rupestres, Chapada Diamantina, fenologia, planta útil, Velloziaceae

ABSTRACT

(Post-fire flowering and fruiting in *Vellozia sincorana*, a caulescent rosette plant endemic to Northeast Brazil). *Vellozia sincorana* L.B. Sm. & Ayensu, an endemic of *campos rupestres*, is an endangered species collected by local people to start cooking fires due to the flammability of its resinous stems. A massive flowering of *V. sincorana* following a wildfire in October 1999 raised some questions: Does fire affect flowering and fruiting of *V. sincorana*? Is the height of individuals correlated with flowering and fruit production? A wildfire event on 8 November 2008 provided an opportunity to explore these questions. Two populations of *V. sincorana* in two *campos rupestres* sites (12º31'S - 41º29'W; 12º36'S - 41º28'W) on ridgetops in the Chapada Diamantina National Park (Brazil) were monitored, one burned in the November 2008 fire and the other unburned since the 1999 fire. In both sites, 25 individuals were randomly labeled and monitored. Nine plant samplings were conducted between 2008 and 2010, during which the number of flowers and fruits were tallied and the heights measured. Spearman's rank correlation coefficient and linear regression were used to evaluate the relationship between the height of individuals and phenology. Flowering and fruiting occurred only in the recently burnt population, about 40 days after the fire, in 24 of the 25 individuals monitored (96%). The quantity of flower and/or fruit was positively and significantly correlated with plant height. The abundant flowering after fire suggests that fire triggers this phenological phase. Estimates of age of the taller individuals and the periods of flowering can be used to estimate fire frequency in the *V. sincorana* population sites, which contributes to the knowledge of fire ecology and is useful for conservation biology and fire management of *campos rupestres*.

Key words: Chapada Diamantina, phenology, rupestrian fields, useful plant, Velloziaceae

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Introduction

Vellozia sincorana (Velloziaceae), or *candombá*, is a species endemic to *campos rupestres* of the Chapada Diamantina (Bahia State, NE Brazil) (Smith & Ayensu 1976), and is collected by local people to start cooking fires because of its resinous stems (Alves 1994; Funch *et al.* 2004). Other species of the same habit have been described as resistant to fire, with the capacity to resprout their leaf rosette after burning, and flower considerably following a fire (Lamont & Downes 1979; Givnish *et al.* 1986; Curtis 1998; Taylor *et al.* 1998; Mello-Silva 2004), with taller individuals flowering more than shorter ones (Curtis 1998; Lamont *et al.* 2000).

Several papers report the importance of fire in the sexual reproduction of plant species in different ecosystems (Coutinho 1977; Lamont & Downes 1979; Pyke 1983; Givnish *et al.* 1986; Johnson *et al.* 1994; Taylor *et al.* 1998; Lamont *et al.* 2000; Verboom *et al.* 2002; Bowen & Pate 2004; Franceschinelli & Bawa 2005; Schmidt *et al.* 2005; Paula & Pausas 2008). However, fire is also viewed as an undesirable disturbance with negative impacts on the local, regional and even global environment, influencing climatic patterns, and sometimes precipitating changes in vegetation communities, mitigated by ecosystem type, local site characteristics, the season of year, frequency of fire, and the amount of dry combustible material accumulated, among other factors (McNeely *et al.* 1990; Whelan 1995; Ramos-Neto & Pivello 2000; Franceschinelli & Bawa 2005; Pivello 2006; Cochrane 2009).

Fire can destroy the flowers and fruits of a plant, or promote opening of the fruits in serotinous species (Coutinho 1977; Whelan 1995), highlighting the importance of the plant phenophase with the fire. In Brazilian savanna, fires early in the season kill most of seeds of *Heteropterys pteropetala* A. Juss. because they are still attached to the mother-plants, while in mid- and end-fires seeds have already been released and may be buried and protected from extreme temperatures during the burning (Schmidt *et al.* 2005). However, the buried seeds are not an assurance of plant recruitment, at least for *Vellozia alata* L.B. Sm., because the potential for germination of its seeds decreases in few months (Munné-Bosch *et al.* 2011). Velloziaceae is an important family for conservation biology (Munné-Bosch *et al.* 2011), with 211 species from Brazil, of which 208 are endemic to this country (Mello-Silva 2010). *Vellozia sincorana* is a threatened species, is endemic to *campos rupestres* in Bahia, and its populations are under pressure from human activities (Funch *et al.* 2004).

The botanical description of *V. sincorana* was made in 1976 based on single voucher from the Chapada Diamantina (Smith & Ayensu 1976). This scarcity of botanical material may be related to the limited geographic distribution of this species, or more likely to the flowering time, if this is restricted to burning episodes. Additionally, other species from the same genus have massive yet very brief blooming phases that offer a lot of resources to a diversity of insects (Mello-Silva 2004; Jacobi & Sarto 2007).

This study aims to answer two main questions. Does fire affect the flowering and fruiting of *V. sincorana*? Is the height of individuals correlated with flowering and fruit production?

Material and methods

This study was carried out in two sites of *campos rupestres* (rocky savannas or rupestrian fields) in the Serra do Sincorá (Sincorá Range), in the municipality of Palmeiras, Chapada Diamantina National Park, in the state of Bahia, in northeastern Brazil, which has elevations between 1040 to 1200 m a.s.l. (Fig. 1). Sandstone and quartzites formed in the Pre-Cambrian, characterized by markedly differential erosion rates, make up the rugged topography of the Chapada Diamantina (Moreira & Camelier 1977).

The climate at the study sites is mesothermic, with a humid summer and four to five dry months concentrated during the winter. From June to August (winter), conditions are cooler and the early morning hours are often cloudy. Mean annual temperatures at locations with elevations between 1000 and 1100 m are lower than 20°C, and minimum daily temperatures lower than 4°C may occur (Nimer 1989). The rainfall measured by the "Orquidário do Pai Inácio" Weather Station (12°27'S – 41°27'W, 885 m a.s.l.) (Fig. 2), which is 6 and 9 km from the study sites, shows the regional precipitation highlighting the wet (December to April) and dry (June to October) seasons, as well as anomalously high rainfall in October 2009.

Campos rupestres physiognomies are a mix of herbaceous and shrubby plant communities, including grass-dominated ones. These occur predominantly on sandy soils, islands of vegetation on rock outcrops, and in the shrubby-grassy continuous vegetation boundary found among rock outcrops (Conceição & Pirani 2005; Conceição *et al.* 2007b; Neves & Conceição 2010).

The two *campos rupestres* sites in the Serra do Sincorá were selected because of: a) relatively high concentration of the target species; b) proximity between them; and c) similarities in habitat, including key biophysical characteristics (elevation, slope, aspect, soils, climate, and vegetation structure) with the exception of fire history. The recently burned site is located at Morro dos Ventos (12°31'S; 41° 29'W); the wildfire occurred 15 days prior to data collection, on 8 November 2008 (Fig. 1). The second site is located near Cachoeira da Fumaça (12°36'S; 41°28'W); this site had a wildfire ten years prior to the data collection period. The distance between the sites is 7 km.

In both sites, 25 individual plants of *V. sincorana* (n = 50) were randomly selected and labeled for repeated observations timed to capture the rapid post-fire onset of flowering and subsequent fruiting, as reported in other species of this family (Jacobi & Sarto 2007). Three visits in

2008 (23 November; 7 and 30 December), five in 2009 (25 January, 24 February, 7 March, 3 May, 6 November) and one in 2010 (25 January) were carried out. Measurements included numbers of flowers and fruits per individual and per branch. Individuals of this species usually have more than one aerial branch, including the old leaf-bases from rosettes (Smith & Ayensu 1976). The fruit is a capsule and the presence of seedy and seedless capsules per individual was identified in the field. The longest and shortest branches of each individual were measured.

Spearman's rank correlation coefficients, and linear regression, were used to evaluate the relationship between an individual's maximum height (based on the longest branch) and minimum height (based on shortest branch) and the range of height determined by difference of height of the longest and shortest branches (independent variables) and two dependent variables: the number of flowers and/or fruits and fertile branches (the number of branches in flowering and/or fruiting). The Kolmorogov-Smirnov test was used to confirm the assumption of normality ($p < 0,05$). Calculations were performed with Systat (version 12.02.00 Systat Inc, San Jose, CA, US).

Results

The 25 adult individuals of *V. sincorana* burnt in Morro dos Ventos on 8 November 2008 survived, and their rosette leaves resprouted rapidly, on the extremes of aerial branches, 15 days after fire (Fig. 1). Flowering and/or fruiting occurred on 24 of the 25 individuals (96%) within approximately 40 days of the 8 November 2008 wildfire (Fig. 3). By contrast, no flowering or fruiting occurred in the population near Cachoeira da Fumaça, which had not experienced a wildfire in ten years.

Observations on 7 December 2008 (no flowers) and 30 December 2008 (50 flowers and 511 fruits) revealed that the plants produced a minimum 511 flowers between 8 and 29 December; no direct observations were made between sampling periods (Fig. 4). Observations of flower and fruit visitation and predation by insects suggest that the overall resources available to animals are potentially higher. In 25 January 2009 (79 days after the fire), 530 fruits and no flowers were observed. These observations highlight the short flowering period observed (approximately 30 days) for this species (Fig. 4). From 200 branches with leaves (8.0 ± 3.74), 77.5% had flowers and fruits on 30 December 2008 (53 days after the fire) and 72% had them on 25 January 2009 (79 days after the fire). All individuals that flowered had fruits, with 1 to 7 flowers/fruits per branch. On 30 December 2008 there were 511 seedy capsules. On 24 February 2009 there were 509 capsules, 45 capsules contained seeds. On 3 May 2009 there were 505 capsules attached to the 24 individuals, but none contained seeds. After one year of fruit production, there were 490 seedless capsules (97%) attached to the branches (Fig. 3 and 4).

The total number of flowers and/or fruits and the number of fertile branches were positively and significantly correlated with the range of height and the maximum height of individuals (Tab. 1). The regression between plant height and the presence of flowers and/or fruits on individuals was not performed because of the high ratio of flowering and fruiting (24/25). The normal distribution was confirmed and the regressions were significant in maximum height and range of height (Fig. 5). The distribution of minimum height regression was not normal. The single individual that did not flower was the one with the shortest branches in the sample set (ranging from 40 to 50 cm). The two tallest individuals had branches between 60 and 100 cm height. The mean branch height among all 25 individuals was 77.3 cm (SD = 14). The mean number of fertile branches per individual was 6.2 (SD = 3.6).

Discussion

The clear difference in flowering and fruiting between the recently burned site and the site observed 10 years after a fire suggest that fire is a key factor for *V. sincorana* flowering and reproduction. While fire appears to be the dominant control on the timing of flowering, other factors such as temperature, photoperiod and precipitation should also be investigated for their contribution to regulating the timing of flowering after a fire. In other Velloziaceae species, flowering is correlated with climatic factors (Conceição *et al.* 2007a), and may have a supplementary influence on phenological timing in this case. During this study period, the rainfall accumulated between fire occurrence and the major flowering event (45 days) was high (206 mm). In *Xanthorrhoea fulva* (A.Lee) Bedford, a plant with a stem rosette from Australia, there was a seasonal effect of fire on the timing of flowering; however, the time to inflorescence production was similar for the summer and spring fires, which was about six months (Taylor *et al.* 1998). Fire interval is another important feature because the percentage of plants in flower declines as the time since the last burn increases (Pyke 1983; Taylor *et al.* 1998).

The specialized root and rosette system of *V. sincorana* may help this species maximize the use of available moisture in order to have a massive flowering phase soon after a fire. Adventitious roots sprout from the living portion of the stem, growing downward through the dead dry leaf matter that forms the caudex (Fig. 1B; Smith & Ayensu 1976; Alves 1994). These are able to gather moisture from fog and rain and at the same time protect the stem from fires (Kubitzki 1998). *Vellozia* species have a *velamen radicum* that has been reported to aid in absorbing atmospheric moisture and is important for water uptake (Porembski & Barthlott 1995). The stem rosette is a typical monocotyledonous life-form from mountains that periodically burn (Lamont & Downes 1979; Givnish *et al.* 1986; Ramsay & Oxley 1996; Curtis 1998; Taylor *et al.* 1998; Safford 2001; Kolbek & Alves

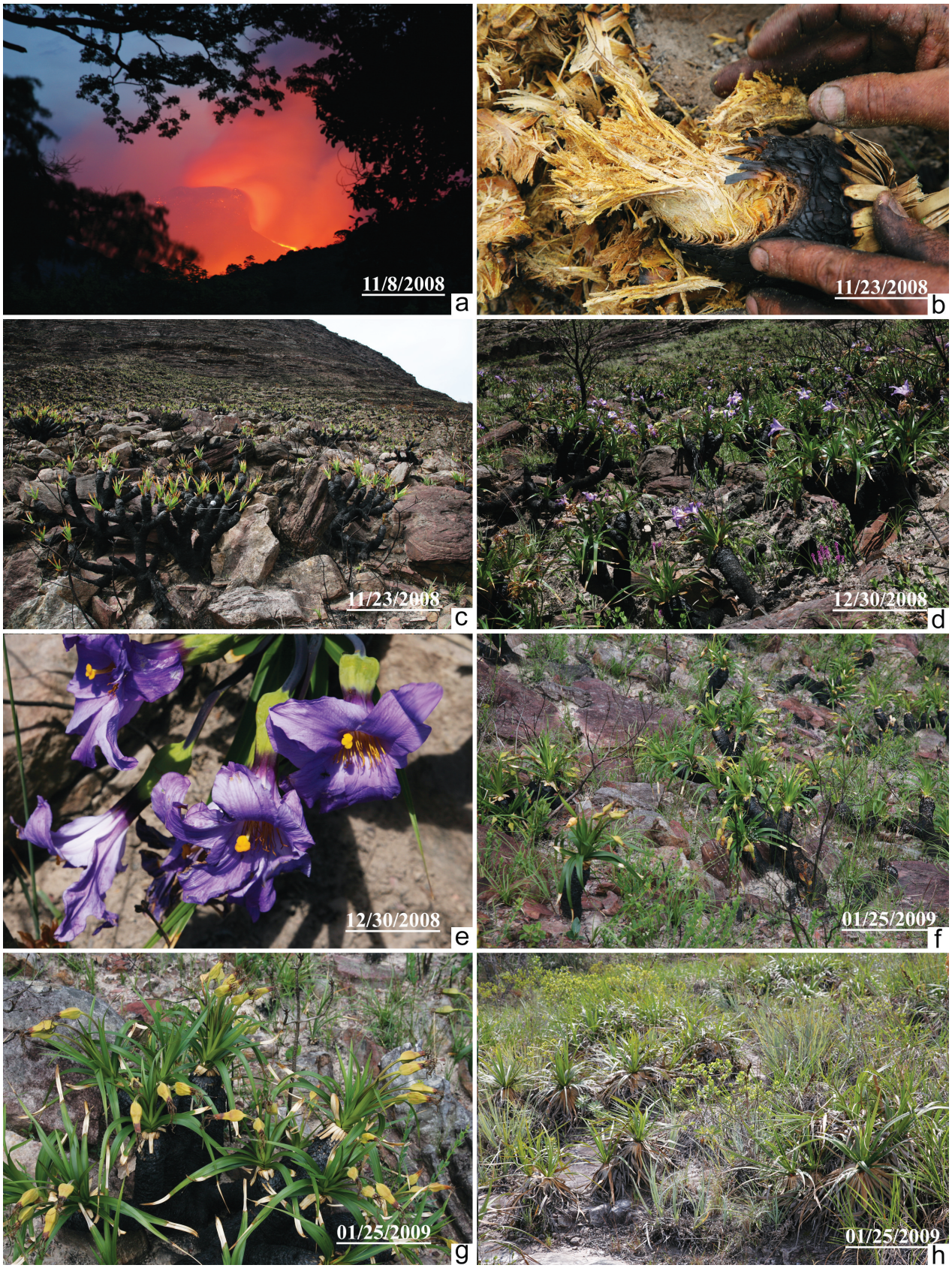

Figure 1. *Vellozia sincorana* in Chapada Diamantina National Park, Bahia, Brazil. (A-G) Burned population in Morro dos Ventos (12°31'S – 41°29'W) at 1040 m a.s.l. (A) Fire occurred on 8 November 2008. (B) Branches used to start cooking fires. (C-G) Time sequence of aerial branch resprouts, flowering and fruiting. (H) Control population near Cachoeira da Fumaça (12°36'S – 41°28'W) at 1200 m a.s.l.

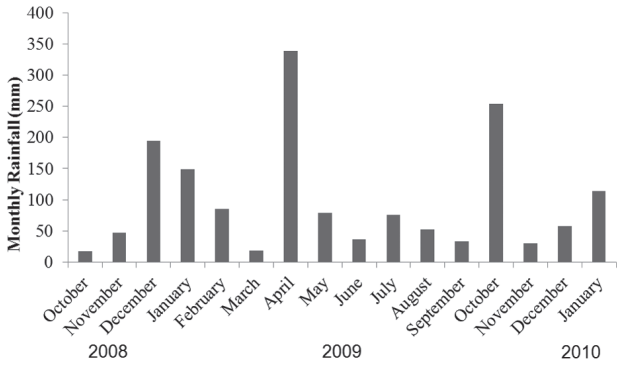

Figure 2. Monthly rainfall from October 2008 to February 2010 in Chapada Diamantina, Bahia, Brazil. Source: Orquidário do Pai Inácio Weather Station (12°27'S – 41°27'W, 885 m a.s.l.).

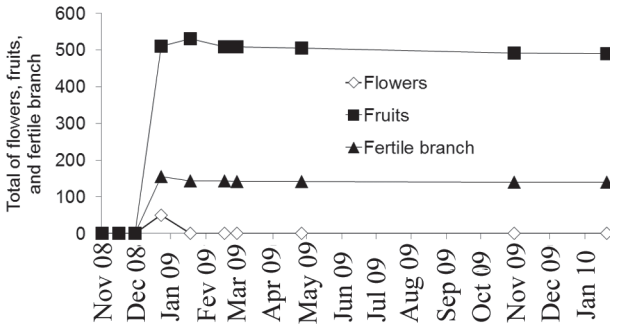

Figure 4. Total flowers, fruits, and fertile branches from 25 individuals of *Vellozia sincorana* that were burned in Morro dos Ventos, Chapada Diamantina National Park, Bahia, Brazil. The symbols correspond to the nine sequential observations after the 08 November 2008 fire.

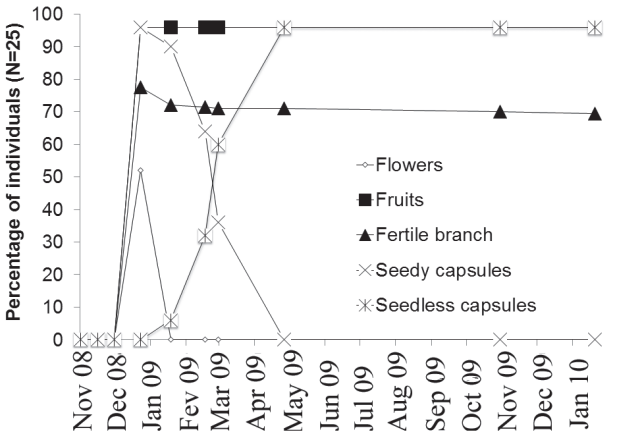

Figure 3. Percentage of 25 individuals of *Vellozia sincorana* with flowers and fruits, and the percentage of fertile branches among 200 branches assessed that resprouted at the burned site in Morro dos Ventos, Chapada Diamantina National Park, Bahia, Brazil. The symbols correspond to the nine sequential observations after the 8 November 2008 fire.

2008). However, other species in the Velloziaceae that are endemic to the rocky savanna of the Chapada Diamantina, such as *Vellozia punctulata* Seub., are sensitive to fire (Neves & Conceição 2010).

Post-fire flowering of *Vellozia sincorana* contributes to how the ecosystem functions in the *campos rupestres* where they grow. The abundant flowering and fruiting in the weeks immediately following a fire creates a sudden, abundant supply of resources for local fauna. This, in turn, can have a positive system-wide effect on pollination and fruit production (Franceschinelli & Bawa 2005). Seed dispersal during the wet season and the pulse of nutrients after burning (Johnson *et al.* 1994; Whelan 1995) may benefit the germination and establishment of plants following fires that occur at the end of the dry season, which happened in this study of *V. sincorana*. The seeds of *V. sincorana* were released *ca.* six months before the dry season, which corresponded to a period of decreasing potential for the germination of *V. alata* (Munné-Bosch *et al.* 2011).

During this study no seed germination or plant establishment were observed, despite the high number of seeds on the ground near the mother-plants. This fact may be due to the high amount of rain in April 2009 (Fig. 2) that could have carried away the seeds; other *Vellozia* species from *campos rupestres* germinate under a wide range of temperature and light and are compatible with this kind of ecosystem (Garcia & Diniz 2003). Regardless of wildfire, the community has a high proportion of *V. sincorana* (Fig. 1), and possibly root competition and shading by *V. sincorana* individuals has a negative effect on establishment, as with sprouts of *Erica multiflora* L. (Montserrat 1997).

The occurrence of more flowers and/or fruits on taller individuals may be correlated with fire and fire temperature, since the most combustible part of this kind of vegetation is physically near the ground (Conceição & Pirani 2005; Midgley *et al.* 2010), where higher temperatures probably occur. As such, the reproductive plant parts of taller individuals can escape from higher temperatures. Taller (and therefore larger) individuals suggest a greater capacity for concentration of nutrient and water reserves, and greater visibility of the flowers to pollinators. Higher flowering of taller individuals may also be explained by correspondingly greater branch volume, which provides more area for flowering.

It is useful to know whether fire is an essential condition to flowering, as this research suggests for *V. sincorana*. Other species that flower after a fire may also flower sporadically, as with an Australian monocotyledon (*Blandfordia nobilis* Sm.) (Johnson *et al.* 1994), two species with stem rosettes [*Xanthorrhoea australis* R.Br. (Curtis 1998) and *X. fulva* (Taylor *et al.* 1998)], and a eudicotyledonous undershrub (*Stirlingia latifolia* R.Br., Bowen & Pate 2004). A monocotyledon endemic of the fynbos in South Africa (*Ehrharta capensis* Thunb*)* was shown to flower after pruning its leafs and providing it with nutrients, supporting the idea of that shoot destruction and changes in soil attributes are features related to high flowering after a fire in some species (Verboom *et al.* 2002). In Australia, the burning and clipping of tufted leaves stimulated inflorescence production of *X. fulva* (Taylor *et al.* 1998).

Table 1. Spearman ranks correlation (r_s) between plant height variables and total number of flowers and fruits and total number of branches with flowers and fruits, for 25 individuals of *Vellozia sincorana* (Velloziaceae) that were sampled on 30 December 2008 in the Serra do Sincorá, Bahia, Brazil.

	Maximum height	Minimum height	Amplitude of height
Total number of flowers and/or fruits	0.541*	-0.234	0.711*
Total number of branches in flowering and/or fruiting	0.631*	-0.211	0.741*

*Significant correlation ($P < 0.05$).

During more than ten years of study in the *campos rupestres* of the Chapada Diamantina, we observed *V. sincorana* flowering events on only two occasions, both following wildfires, including the one in this study (2008) and another following a large fire in a population in Cachoeira da Fumaça (1999). After the 1999 fire, like in 2008, flowering was observed only in individuals located in burned areas. Also, like in 2008, the vast majority of of these individuals flowered.

The importance of fire in savanna has been well established (Ramos-Neto & Pivello 2000; Pivello 2006; Simon *et al.* 2009; Midgley *et al.* 2010). Prior studies of post-fire phenological response, with the exception of *Stirlingia latifolia*, an Australian species of Proteaceae (Bowen & Pate 2004), did not report the exceptionally high degree of flowering that was observed for *V. sincorana* in the present study (*e.g.*, Lamont & Downes 1979; Givnish *et al.* 1986; Johnson *et al.* 1994; Curtis 1998; Taylor *et al.* 1998; Lamont *et al.* 2000; Franceschinelli & Bawa 2005).

Anatomical studies to identify flowering and fire episodes on the older, longest branches of *V. sincorana* could make it possible to infer *campos rupestres* fire frequency by merging age information (as much as 100 years old in other Velloziaceae species) (Alves 1994), presence of charcoal, and flowering triggered by fire (Lamont & Downes 1979; Müller 2006). The two most recent episodes of fire in the Morro dos Ventos population (1999 and 2008) are known and could be used to calibrate fire frequency estimates. This information, acquired for many sites, can help explain ecological processes in savannas in support of fire management and biodiversity conservation. Recent research on the genetic variations of populations of other *Vellozia* species in *campos rupestres* stressed the importance of genetic diversity of these species to habitat preservation (Franceschinelli *et al.* 2006), which is influenced by fire occurrence. Fire occurrence can have a general and sporadic influence on the dispersal and distribution of individuals in time and space, which in turn has a positive effect on diversity (Safford 2001). Illegal and uncontrolled fires, however, can increase fire frequency, leading to mortality in a system otherwise well-adapted to fire, particularly when these unnatural fires occur during an unfavorable season for the vegetation (Whelan 1995; Curtis 1998; Lamont *et al.* 2000; Ramos-Neto & Pivello 2000; Franceschinelli & Bawa 2005; Pivello 2006). Understanding the relationship between fire and phenology of a species is important for *campos rupestres*' ecosystem function, as well as the lives of local people can provide insights important to fire ecology that can support both conservation and more sustainable use.

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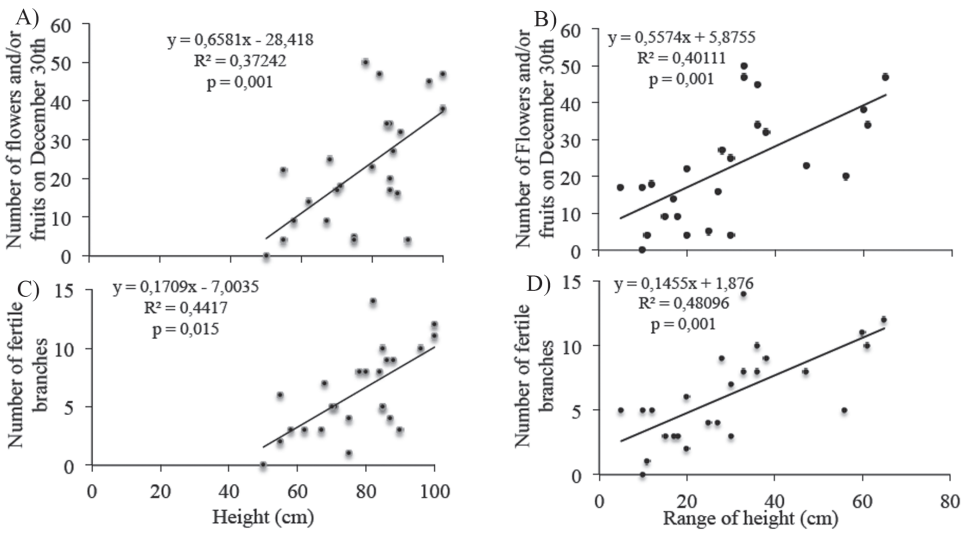

Figure 5. Linear regression between plant height and two factors: the total number of flowers and fruits (a, c), and the total of branches with flowers and fruits (b, d) of 25 individuals of *Vellozia sincorana* in Morro dos Ventos, Chapada Diamantina National Park, Bahia, Brazil.

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