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Hailstorm impact across plant taxa: Leaf fall in a mountain environment

Impacto de uma tempestade de granizo em diferentes táxons vegetais: queda foliar em um ambiente de montanha

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Abstract

Natural catastrophes in the planet increased over 400% from 1970 to 2005, causing severe impact on natural ecosystems, and are sought to increase in the forthcoming decades due to climate change driven events. However, the descriptions of the impacts caused by events as hailstorms on wild ecosystems are anecdotal in the tropical region. The occurrence of a severe hailstorm on a mountainous tropical environment in Brazil allowed, for the first time, to examine hailstorm impact on 32 plant species belonging to distinct families. The study was carried out in an area of rupestrian field located in Serra do Cipó, Minas Gerais State, Brazil. The impact of hail on the vegetation was evaluated by an index of damage and the damage level was related to plant species architectural features. Hail impact differed strongly among the species and was influenced by plant height, growth form, leaf traits and stem type. Hailstorms are natural disturbance phenomena that have differential impacts on plants species in rupestrian fields.

Key words: climate change, hailstorm damage, plant resistance, rupestrian fields, Serra do Cipó.

Resumo

As catástrofes naturais no planeta cresceram mais de 400% de 1970 a 2005, causando severo impacto sobre os ecossistemas naturais, sendo previsto um aumento destes eventos nas próximas décadas devido às mudanças climáticas. No entanto, as descrições dos impactos causados por eventos como os granizos sobre ecossistemas naturais na região tropical são inexistentes. A ocorrência de uma severa tempestade de granizo em um ambiente tropical montanhoso no Brasil permitiu, pela primeira vez, avaliar o impacto da chuva de granizo em 32 espécies de plantas pertencentes a diversas famílias. O estudo foi realizado em uma área de campo rupestre na Serra do Cipó, Minas Gerais, Brasil. O impacto da chuva de granizo foi avaliado a partir de um índice de danos e o nível de dano foi relacionado com as características arquitetônicas das espécies vegetais O impacto de granizo diferiu fortemente entre as espécies e foi influenciado por altura da planta, forma de crescimento, atributos foliares e do tipo de caule. As chuvas de granizo são fenômenos naturais de distúrbio com impactos diferenciados sobre as espécies vegetais no campo rupestre.

Palavras-chaves: mudanças climáticas, danos da chuva de granizo, resistência vegetal, campo rupestre, Serra do Cipó.

Introduction

Records of substantial impact and damage on nature caused by unexpected and intense climatic disturbances have been reported throughout history. However, the frequency and intensity of these events seem to have been intensifying in the last decades (Bauer-Messmer and Waldvogel, 1997) and human-induced climate change has been argued to be associated with it (Crompton and Aneney, 2008). Natural catastrophes in the planet increased over 400% from 1970 to 2005 (Zanetti and Schwarz, 2006, Figure 1).

Global climatic simulation models indicate an increase of maximum and minimum temperature, modification in precipitation parameters (more intense precipitation or severe drought), increase of tropical cyclones and events related with El Niño, abrupt climate changes, increase in the frequency and intensity of several types of storms such as hurricanes, tornados, thunderstorms, windstorms and hailstorms (e.g., Carter *et al*., 1999).

Hailstorms frequently occur during the spring and summer when the temperatures are higher and more water vapor is available in the atmosphere (Berlato *et al*., 2000; Nobre, 2001). These phenomena can take place when the rising of the temperature in the closer atmospheric zone layers retains more water vapor causing an acceleration of the hydrologic cycle that promotes severe storms (Nobre, 2001). However, the occurrence of hailstorms is due to multiple factors that involve topographic features, altitude, and temperature, among others (Dale *et al*., 2001). According to Nobre (2001) the frequency of extreme climatic events in South America is uncertain. It is expected, however, that due to the temperature increase in the atmospheric layers near the surface, an increase in the number of hailstorms in the region.

Hail may cause significant impact on vegetation, but as plants live on different habitat conditions and present different traits and architecture, the impact is also expected to differ among them. The most visible impact is at the leaf level due to the loss of leaf area available to photosynthesis caused by the laceration of the leaf lamina or its complete removal (Dwyer *et al*., 1994). Depending on the ontogenetic development and phenology at the time of the hail event the reproductive structures, fruits and flowers, as well as growth modules (meristems) can be totally destroyed (Whiteside *et al.,* 1988). Stems can also suffer intense damage or even complete removal by hailing. Moreover, small lesions can lead to sores and injures few days after the event and the sores caused by impact of hails on plants represent sites for the entrance of diverse pathogenic infections (Jones and Aldwinkle, 1990). At the stand level in a temperate forest environment, damage induced by hailstorms is highly variable depending on stand species composition, amount and extent of ice accumulation, and historical context (Irland, 1998). Peltzer and Wilson (2006) observed that grasses and lichens suffered much higher rate of biomass removal (60-76%) than shrubs (6-8%) after a hailstorm on native grassland in the northern Great Plains of North America. Effects on vegetation involve changes in the composition of species towards more resistant plants species, establishment of new leaves and the recovery of the stems (Peltzer and Wilson, 2006). The recovery after a severe hailstorm appears to be slow, as exemplified by *Larrea cuneifolia* that needed 207 days to recover the initial dry weight after a hail storm (Méndez, 2003).

At a physiological or adaptation perspective, the knowledge of hailstorm impact on wild plant species is anecdotal at best. Otherwise, some physiological alterations such as changes in photosynthetic rate, chlorophyll and secondary compounds have been observed after hailing. The torn edges, caused by hailstorm, become predominant sites of unregulated water loss for the plant. Tartachnyk and Blanke (2008) showed that prompt stomata closure in the leaf area around the damage sites took place within 3 min after hail injury and led to a decline in evapotranspiration and a severe reduction in photosynthetic CO_2 assimilation. Recovery in both transpiration and photosynthesis commenced after 3h. It remained unclear, however, whether the observed decrease in photosynthetic CO_2 assimilation was due exclusively to stomatal limitation preventing entry of CO_2 into the leaf or, additionally, to limitations in primary photochemical

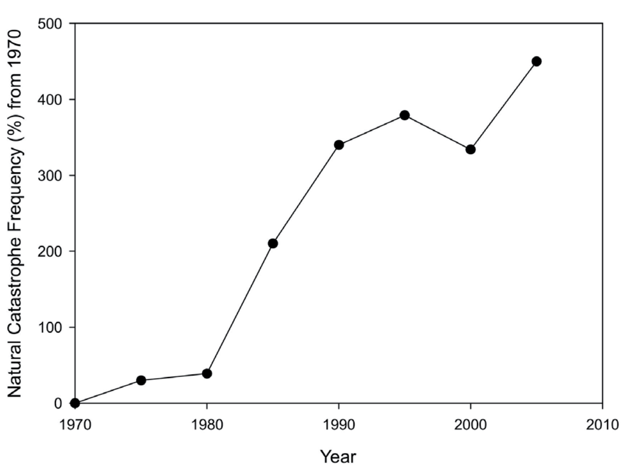

Figure 1. Percentage of increase of natural catastrophes during 1970 to 2005 (calculated from data of Zanetti and Schwarz, 2006).

processes. Hailstorms can also provoke alterations in the ecological dynamics of an ecosystem (Peltzer and Wilson, 2006) and consequently affect the ecological succession process, at least temporally according to impact and frequency of hailstorm.

Most hailstorms hit regions where their impact is not recorded and, as a consequence, the knowledge on potential damage caused on plants in natural ecosystems remains unrecorded. In the tropics most studies are concentrated in crop species (Jakopic *et al.*, 2007; Tartachnyk and Blanke, 2008). However, these plants might not offer reliable comparisons with wild species in their natural habitat conditions as through human selection, these plants present different architecture, and are selected for some attributes, generally not found on their wild relatives. On September 15th, 2008, a strong hailstorm hit an area comprehended between 1000 and 1300 meters high in elevation in Serra do Cipó, southeastern Brazil (Figure 2). The phenomenon was recorded on a small area in the elevation gradient of approximately 30-50 km² (19º 16' 45.7"S and 43º 35' 27.8" W). Despite the small area affected, the vegetation was visibly impacted by the storm. The event provided an unforeseen opportunity to study the response of native plants to this natural disturbance. The vegetation hit by the hailstorm, rupestrian field, is one of the richest on species in the tropics and has a high level of endemism and biodiversity (Giulietti *et al.*, 1997). The rich community of herbaceous and woody species are mainly composed of sclerophyllous plants with tortuous trunks, are exposed to severe abiotic conditions that include strong winds, frequent fires, low humidity during the dry season, high temperature variation during the day, high light exposure, and extremely poor soils (Giulietti *et al.*, 1997; Ribeiro and Fernandes, 2000).

In an attempt to provide the first data on the impact and relevance of hailstorm on the speciose and endemic plant community, we evaluated the level of impact of hails on 32 plant species and individual plant traits, such as plant height, growth form, leaf traits and stem type. We aimed to test the following hypotheses: (i) taller plant individuals suffer higher damage than shorter individuals because they are more exposed to hail, independent of plant species; (ii) herbaceous species are more vulnerable to the impact of hailing; and (iii) leaf traits, such as shape and arrangement, and type of stems influence on the intensity of leaf damage caused by hailstorm.

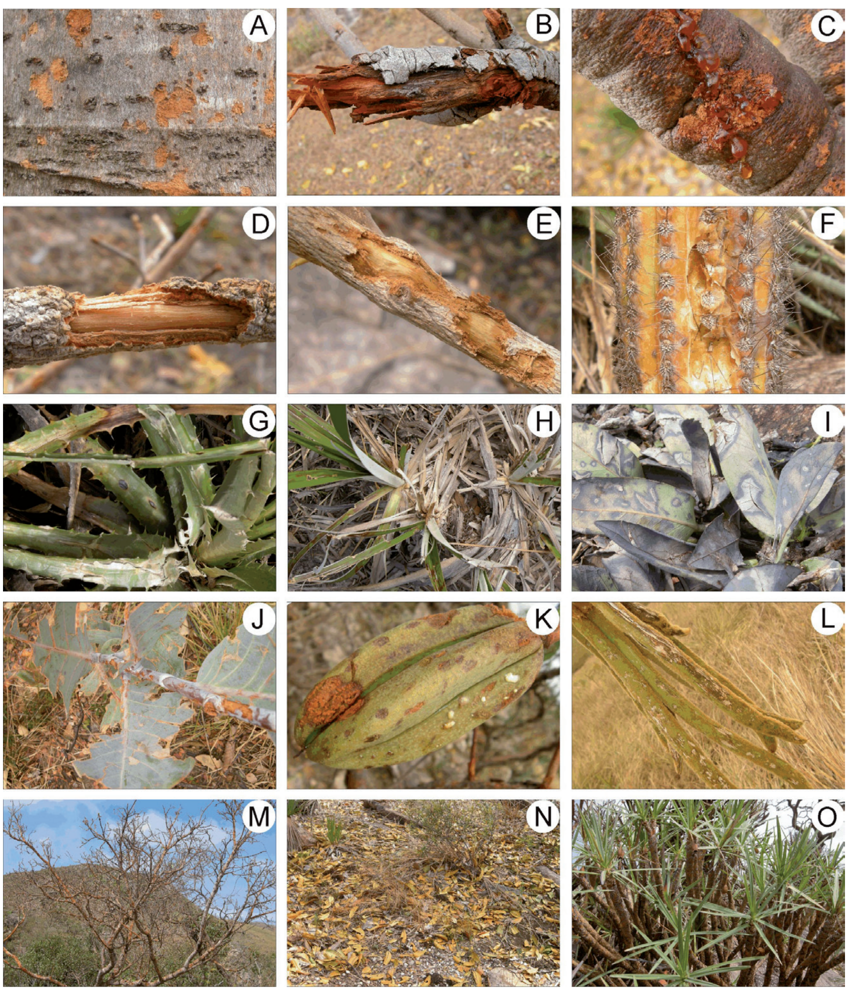

Figure 2. Damages caused by hailstorm on rupestrian field vegetation species: (A) *Cecropia pachystachya* (trunk); (B) and (C) *Stryphnodendron adstringens* (branches and trunk); (D) *Leiothrix spiralis* (branches); (E) *Miconia* sp.(branches); (F) *Pilosocereus auristeus* (individual); (G) *Dyckia* sp. (leaves); (H) *Vellozia nivea* (leaves); (I) *Neea theifera* (leaves); (J) *Coccoloba cereifera* (leaves); (K) *Kielmeyera petiolaris* (fruits); (L) *Tabebuia ochracea* (fruits); (M) *Byrsonima verbascifolia* (individual); (N) Green fall; (O) *Vellozia compacta* (individual).

Material and methods

Site description

The field sample was carried out on September 19, 2008, four days after the hailstorm, in the Vellozia Reserve (19º 16' 45.7"S and 43º 35' 27.8" W), located in Serra do Cipó, southern portion of the Espinhaço Range, Minas Gerais State, Brazil. The vegetation of the study site is the rupestrian fields (rocky outcrops at high elevations) (for further details see Giulietti *et al.*, 1997; Ribeiro and Fernandes, 2000).

Damage evaluation and pertinent plant characteristics

The effects of the hailstorm on the rupestrian field vegetation were evaluated on the 32 plant species most frequent in the studied area. Damage was categorized according to (i) damage level (classified according to field analysis of the impact), and (ii) survey of the habit and morphological traits of each plant species that could influence the degree of damage observed in the sample. In the field, up to 10 individuals of each species were examined considering the parameters: height of the individual and the level of damage (leaf loss). Damage level evaluation on leaves was done through an adaptation of the categories based on Dirzo and Dominguez (1995) as 0 = no leaf loss; 1 = 1-6%, 2 = 7-12%, 3 = 13-25%, 4 = 26-50%, 5 = 51-100%. The height and the leaf loss category of each individual were recorded. For each family, the individual frequency in each category of leaf damage after a hailstorm was calculated.

To analyze the plant traits that could confer resistance to hail impact, we collect secondary information on each plant species studied from the literature on taxonomy and systematic botany, and obtained assistance from the Botanical Herbarium from Instituto de Ciências Biológicas, Universidade Federal de Minas Gerais. The plant aspects analyzed were: family, growth habit (herb, shrub or tree), leaf traits, and stem type. Leaves were separated according to: leaf attachment (petiolate or sessile), leaf shape (single or compound), leaf arrangement on the stem (alternate and opposite) and leaf texture (membranous, chartaceous, coriaceous and succulent). Stem (woody, stipe, acaule, succulent) was classified as to type. From the data collected we evaluated the frequency of individuals with each plant feature relative to categories of leaf loss.

For comparison among the height of the individuals (non-parametric data) observed in each categories of leaf loss, we used the non-parametric test of Kruskal-Wallis (Conover, 1980). The average ordinations (rank mean) were compared by the Dunn test. Chi-square tests (X^2) were conducted for the comparison between the frequencies of individual with each plant feature relative to categories of leaf loss. The statistical tests were performed through the Sigma Stat for Windows version 3.5 (Copyright © 2006 Systat Software Inc).

Results

The 32 species analyzed (Table 1, n=10 individuals per species) belong to 20 plant families. The plant species in the familes Clusiaceae, Nyctaginaceae, Mimosoidae, and Erythroxylaceae were the most highly impacted, suffering leaf losses that ranged from 90 to 100%. No apparent physical damage was observed on individuals of the Bromeliaceae, Cactaceae and Rubiaceae (Table 2).

The data indicate that leaf loss varied according to some plant traits. The lowest rates of leaf loss caused by hailstorm were found on the shorter individuals (Figure 3, $P< 0.01$) and on herbaceous species ($X^2= 71.5$, degree of freedom (df) = 10, $P = <0.001$; Figure 4a). Individuals with petiolate leaves suffered greater loss of leaves than individuals with sessile leaves (ca. 60% of the sessile individuals suffered no damage) ($X^2= 79.0$, df= 5, $P = <0.001$; Figure 4b). The shape and the arrangement of leaves also influenced leaf loss by hail. The individuals with compound leaves ($X^2= 19.1$, df= 5, $P = 0.002$; Figure 4c) and opposite leaves ($X^2= 109.2$, df= 5, $P = <0.001$; Figure 4d) had higher leaf loss. Species with succulent leaves showed no leaf loss while species with membranous leaves exhibited higher rates of leaf loss ($X^2= 125.2$, df= 15, $P = <0.001$; Figure 4e). The degree of leaf loss was influenced by the type of the plant stem. The frequency of acaule individuals with no damage was high (around 67%), while woody plants with no damage only represented 25% ($X^2= = 98.9$, df= 15, $P = <0.001$; Figure 4f). The most severe damages were found on woody individuals (Figure 4f).

Discussion

Extreme events such as hailstorms cause severe damages on vegetation and produce pronounced leaf loss and laceration of leaves (Whiteside *et al.,* 1988; Jones and Aldwinkle, 1990; Dwyer *et al.,* 1994), as observed in this study. However, hail did not affect plant families homogeneously. In addition, a combination of traits as height, plant habitat, physical features (architecture, leaf hardness) of plant species influenced the degree of hail impact on wild plant species in this ecosystem.

The shorter individuals and herbaceous species were the most resistant to hail. Shorter individuals exhibit lower biomass (Huston, 1997) and canopy area, and hence may lose fewer leaves with a minor probability of being hit by the hails. The herbaceous species found in the rupestrian field are species with tough or coriaceous leaves (Giulietti *et al.*, 1997; Ribeiro and Fernandes, 2000). These traits may minimize leaf loss. For the rupestrian fields some leaf features (sessile, simple, alternate, and succulent leaves) appear to offer more protection against hail impact in this ecosystem. Hailstorms are often accompanied by strong winds and, according to leaf spatial features (attachment, shape, arrangement) and resistance (texture), individuals can suffer different levels of damages. Membranous leaves, due to their thin consistency and lesser thickness, are more vulnerable to damages compared to harder and thicker leaves (see Gonçalves and Lorenzi, 2007). For Cunningham *et al*. (1999), a greater epidermal thickness can allow more leaf resistance (physical reinforcement). Succulent leaves are thicker and have more features such as cuticle developed, which may provide greater protection against environmental damage.

Table 1. List of Plant species studied of the area impacted by hailstorm in the rupestrian fields in Serra do Cipó, Brazil.

Plant species	Plant family	Growth habit	Leaf features				Stem type
			Leaf attachment	Leaf shape	Leaf arrangement on the stem	Leaf texture	
Syagrus glaucescens Becc.	Arecaceae	tree	petiolate	compound	opposite	coriaceous	stipe
Syagrus pleioclada Burret	Arecaceae	tree	petiolate	compound	opposite	coriaceous	stipe
Baccharis dracunculifolia DC.	Asteraceae	shrub	sessile	single	alternate	membranous	woody
Dasyphyllum reticulatum (DC.) Cabrera	Asteraceae	shrub	petiolate	single	alternate	coriaceous	woody
Tabebuia ochracea (Cham.) Standl.	Bignoniaceae	tree	petiolate	compound	opposite	coriaceous	woody
Dyckia sp. (Schult. f.)	Bromeliaceae	herb	sessile	single	alternate	succulent	acaule
Pilosocereus auristeus (Werderm.) Byles and G.D. Rowley	Cactaceae	shrub	sessile	single	spines*	spines*	succulent
Kielmeyera petiolaris Mart. and Zucc.	Clusiaceae	tree	petiolate	single	alternate	coriaceous	woody
Paepalanthus vellozioides Körn.	Eriocaulaceae	herb	sessile	single	alternate	coriaceous	acaule
Leiothrix spiralis Ruhland	Eriocaulaceae	herb	sessile	single	alternate	membranous	acaule
Erythroxylum suberosum A. St.-Hil.	Erythroxylaceae	shrub	petiolate	single	alternate	coriaceous	woody
Humiria balsamifera Aubl.	Humiriaceae	tree	petiolate	single	alternate	coriaceous	woody
Ocotea langsdorffii (Meisn.) Mez	Lauraceae	tree	petiolate	single	alternate	coriaceous	woody
Plathymenia foliosa Benth.	Leguminosae	tree	petiolate	compound	alternate	membranous	woody
Stryphnodendron adstringens (Mart.) Coville	Leguminosae	tree	petiolate	compound	alternate	membranous	woody
Byrsonima verbascifolia (L.) DC.	Malpighiaceae	shrub	sessile	single	opposite	coriaceous	woody
Byrsonima sp1 Rich. ex Juss.	Malpighiaceae	shrub	sessile	single	opposite	coriaceous	woody
Tetrapterys microphylla Nied.	Malpighiaceae	shrub	sessile	compound	opposite	chartaceous	Woody
Miconia sp1 (Ruiz and Pav.)	Melastomataceae	shrub	petiolate	single	opposite	coriaceous	woody
Miconia stenostachya DC.	Melastomataceae	shrub	petiolate	single	opposite	coriaceous	woody
Tibouchina sp1 (Aubl.)	Melastomataceae	shrub	petiolate	single	opposite	coriaceous	woody
Trembleya laniflora (DC.)	Melastomataceae	shrub	petiolate	single	opposite	coriaceous	woody
Myrcia guianensis (O. Berg) McVaugh	Myrtaceae	shrub	petiolate	single	opposite	chartaceous	woody
Neea theifera Oerst.	Nyctaginaceae	shrub	petiolate	single	subopposite	coriaceous	woody
Aulonemia effusa (Hack.) McClure	Poaceae	shrub	petiolate	single	alternate	coriaceous	woody
Sabicea brasiliensis (Aubl.)	Rubiaceae	tree	petiolate	single	opposite	coriaceous	woody
Cecropia pachystachya Trécul	Urticaceae (Cecropiaceae)	tree	sessile	single	alternate	coriaceous	woody
Barbacenia flava Mart.	Velloziaceae	herb	sessile	single	alternate	membranous	woody
Vellozia compacta Mart.	Velloziaceae	herb	sessile	single	alternate	coriaceous	woody
Vellozia nivea L.B. Sm. and Ayensu	Velloziaceae	herb	sessile	single	alternate	chartaceous	woody
Vellozia squamata Pohl	Velloziaceae	herb	sessile	single	alternate	chartaceous	woody
Vochysia thyrsoidea Pohl	Vochysiaceae	tree	petiolate	single	verticillate*	coriaceous	woody

Note: (*) Feature not included in the analysis.

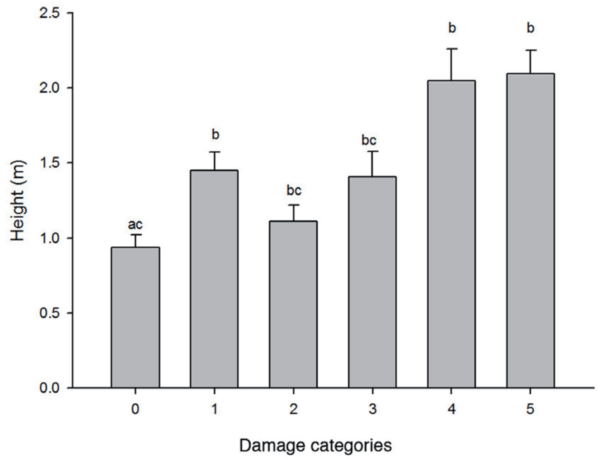

Figure 3. Height of the individuals (mean ± standard error) observed for each category of damages caused by impact of hailstorm on rupestrian field (Kruskal-Wallis test, P< 0.05). Different letters indicate statistical significance.

Table 2. Frequency of individuals with leaf damage by plant family in each category of leaf damage (modified from Dirzo and Dominguez, 1995) after a hailstorm in Serra do Cipó, Minas Gerais, Brazil.

Leaf Category Plant Family	0 (0%)	1 (1-6%)	2 (7-12%)	3 (13-25%)	4 (26-50%)	5 (50-100%)
Arecaceae	35.0	35.0	20.0	10.0	0.0	0.0
Asteraceae	0.0	4.8	0.0	0.0	28.6	**66.7**
Bromeliaceae	**100.0**	0.0	0.0	0.0	0.0	0.0
Cactaceae	**100.0**	0.0	0.0	0.0	0.0	0.0
Clusiaceae	0.0	0.0	0.0	0.0	0.0	**100.0**
Eriocaulaceae	50.0	0.0	0.0	0.0	30.0	20.0
Erythroxylaceae	0.0	0.0	0.0	10.0	0.0	**90.0**
Humiriaceae	14.3	0.0	0.0	0.0	28.6	57.1
Lauraceae	0.0	**70.0**	20.0	10.0	0.0	0.0
Leguminosae	20.0	0.0	20.0	20.0	30.0	10.0
Malpighiaceae	0.0	0.0	16.0	12.0	8.0	64.0
Melastomataceae	0.0	6.3	3.1	15.6	34.4	40.6
Mimosoideae	0.0	0.0	0.0	10.0	0.0	**90.0**
Myrtaceae	**70.0**	0.0	0.0	10.0	0.0	20.0
Nyctaginaceae	0.0	0.0	0.0	0.0	10.0	**90.0**
Poaceae	0.0	0.0	10.0	80.0	10.0	0.0
Rubiaceae	**100.0**	0.0	0.0	0.0	0.0	0.0
Urticaceae	**72.7**	9.1	9.1	9.1	0.0	0.0
Velloziaceae	**76.2**	0.0	0.0	0.0	0.0	23.8
Vochysiaceae	0.0	0.0	0.0	0.0	50.0	50.0

Moreover, the type of stem is another important plant trait that influences the degree of damage caused by hailstorm in the rupestrian fields. Woody plants were more susceptible to hail impact than acaule plants. Woody plants generally present stems which are more rigid and hence have a greater chance to break upon impact by hail, and consequently end up losing a higher leaf area.

Traits such as leaf sclerophylly, architecture (structure and branching patterns of individuals) (Houston, 1999), and the physiological ability to respond to damage (e.g., meristem dynamics) (Mendez, 2003; Tartachnyk and Blanke, 2008) are strong factors associated to damage that plants can sustain. On the other hand, it is important to highlight that the level of hail impact has on plants may vary according to the habitat or ecosystem (Peltzer and Wilson, 2006). The effects of hailstorms on vegetation may involve changes in the composition of species according to their ability to live out and respond to damage (Peltzer and Wilson, 2006). The frequency and relevance of such climatic events are thought to increase in the forthcoming decades due to climate change (McMaster, 1999; Dale *et al*., 2001), and the understanding of these events is of crucial importance for the speciose and fragile habitats generally found in mountain tops worldwide.

Hailstorms represent forces that have the potential to change community structure. The knowledge about the impact hailstorm on speciose ecosystems, as the rupestrian fields, and its recovery is of fundamental importance. The vegetation of this threatened ecosystem is already under high pressure caused by invasive species, road construction, fire and urban expansion. Hailstorm may represent a phenomenon of importance that may become major if its frequency increases in the forthcoming years. Otherwise, data on hail impact on wild plant species are rare at best and, hence,

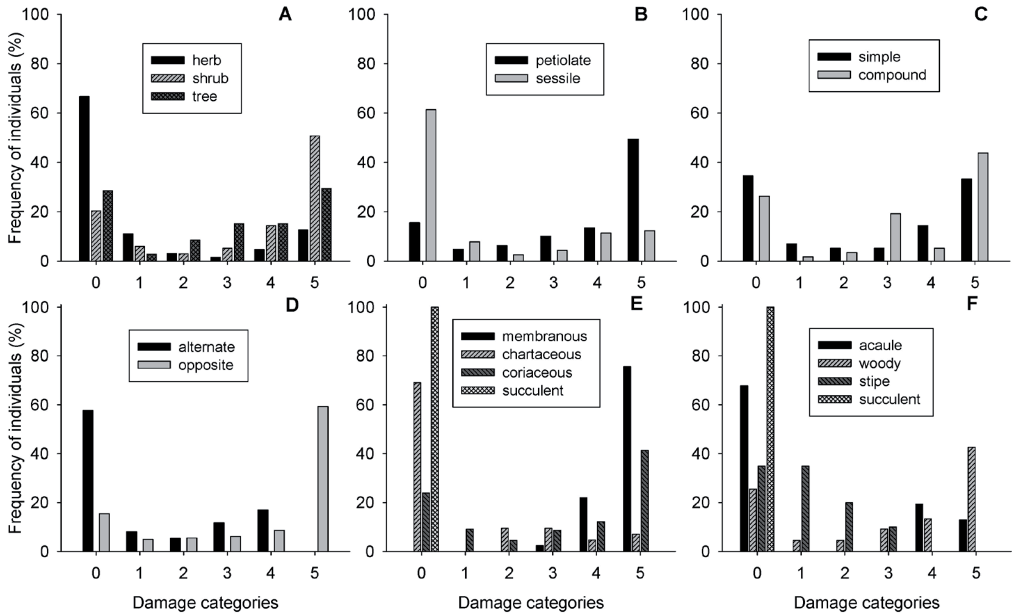

Figure 4. Categories of damages caused by impact of hailstorm on rupestrian field according to (A) frequency of herbs, shrubs, and trees; (B) leaf attachment (petiolate or sessile); (C) leaf shape (simple or compound); (D) leaf arrangement (alternate or opposite); (E) leaf texture (membranous, chartaceous, coriaceous, succulent); and (F) stem type (acaule, woody, stipe, succulent). (Chi-square test, P< 0.05).

there is an urgent need to gather whatever information is available at the moment so that one can attempt to formulate models to predict impact and wild plant species recovery after hailstorm. For the near upcoming future, biologists will be asked to detail their understanding on disturbances caused by climate changes, including how plants, ecosystems and interactions respond to them, and hailstorm might be an important phenomena to be added in the increasing list.

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