Control of ball moss (*Tillandsia recurvata* L.) in fruit trees in the central region of Peru

Control de los henos de motita (*Tillandsia recurvata* L.) en árboles frutales de la región centro del Perú

Controle do feno de motita (*Tillandsia recurvata* L.) em árvores frutíferas na região central do Peru

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Abstract

In the current era, it is common to witness the massive proliferation of epiphytes, particularly the species *Tillandsia recurvata* L., commonly known as ball moss, which adhere in large quantities to fruit trees of various species, affecting fruit growing in the inter-Andean valleys of Peru. This species causes a gradual but constant deterioration of the trunks and branches of the fruit vegetation, causing its eventual death, therefore, the purpose of the present study was to evaluate the combination of sodium bicarbonate, copper sulfate, vinegar, and yeast in the control of *Tillandsia recurvata* L. A completely randomized block design was applied with 10 treatments and 5 repetitions. The following variables were evaluated: weight, moisture loss, and grade of epiphyte damage. The results determined that sodium bicarbonate significantly reduced the weight of *T. recurvata*, decreasing from 2.2 g to 0.26 g; regarding moisture loss, an increase was observed from 25.62 % to 91.65 %, as well as damage and mortality increased significantly with the vinegar + sodium bicarbonate treatment. In conclusion, treatments with sodium bicarbonate and vinegar + sodium bicarbonate caused the greatest damage and mortality in ball moss.

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Resumen

En la época actual, es común presenciar la proliferación masiva de las plantas epífitas, en particular de la especie *Tillandsia recurvata* L.*,* conocidos comúnmente como heno de mota, que se adhieren en gran cantidad a los árboles frutales de diversas especies, afectando la fruticultura en los valles interandinos del Perú. Esta especie provoca un deterioro gradual pero constante de los troncos y ramas de la vegetación frutal, ocasionando su eventual muerte, por lo que, el propósito del presente estudio fue evaluar la combinación del bicarbonato de sodio, sulfato de cobre, vinagre, levadura en el control de *Tillandsia recurvata* L. Se aplicó un diseño de bloques completamente al azar con 10 tratamientos y 5 repeticiones. Se evaluaron las variables: peso, pérdida de humedad y grado de afectación de las epífitas. Los resultados determinaron que el bicarbonato de sodio redujo significativamente el peso de *T. recurvata* disminuyendo de 2,2 g a 0,26 g; en cuanto a la pérdida de humedad, se observó el incremento desde un 25,62 % a 91,65 %, así como los daño y la mortalidad se incrementaron significativamente con el tratamiento vinagre + bicarbonato de sodio. En conclusión, los tratamientos con bicarbonato de sodio y vinagre + bicarbonato de sodio causaron el mayor nivel de daño y mortalidad en los henos de mota.

Palabras clave: *Tillandsia recurvata* L., control de epífitas, bicarbonato de sodio en frutales, uso agrícola del vinagre, heno de mota.

Resumo

Na época atual, é comum assistirmos à proliferação massiva de plantas epífitas, nomeadamente da espécie *Tillandsia recurvata* L., vulgarmente conhecida como feno de mota, que aderem em grandes quantidades a árvores de fruto de diversas espécies, afetando a fruticultura no inter. -Vales andinos do Peru. Esta espécie provoca uma deterioração gradual, mas constante, dos troncos e galhos da vegetação frutífera, causando sua eventual morte, portanto, o objetivo do presente estudo foi avaliar a combinação de bicarbonato de sódio, sulfato de cobre, vinagre, levedura no controle de *Tillandsia recurvata* L. Foi aplicado um projeto de blocos completamente aleatórios com 10 tratamentos e 5 repetições. Foram avaliadas as variáveis: peso, perda de umidade e grau de envolvimento das epífitas. Os resultados determinaram que o bicarbonato de sódio reduziu significativamente o peso de *T. recurvata*, diminuindo de 2,2 g para 0,26 g; em relação à perda de umidade, foi observado um aumento de 25,62 % para 91,65 %, bem como os danos e a mortalidade aumentaram significativamente com o tratamento vinagre + bicarbonato de sódio. Concluindo, os tratamentos com bicarbonato de sódio e vinagre + bicarbonato causaram os maiores níveis de danos e mortalidade nos fenos de mota.

Palavras-chave: *Tillandsia recurvata* L., controle de epífitas, bicarbonato de sódio em fruteiras, uso agrícola de vinagre, feno de capim.

Introduction

The genus *Tillandsia* of the family Bromeliaceae are epiphytic plants, invasive par excellence, and of worldwide distribution with more than 500 species and multiple habitats, some of ornamental importance, benefits in the ecosystem, or invasive plants of trees. In recent decades, the species *T. recurvata* L. (ball moss) has emerged as a problem due to its invasive nature, causing the death of trees (Bartoli *et al*., 1993; Beltrán *et al*., 2020). *Tillandsia recurvata* L. and *Tillandsia usneoides* L. are grayish herbaceous plants that do not depend on soil or substrate for their development, which allows them to grow on almost any surface, even in electrical wiring networks (Gámez-Vázquez *et al*., 2022; Ceballos, 2023). They do not possess a conventional root system, instead, they develop specialized structures called “rhizoids” that function as anchors to various structures where they grow. It has been shown that ball moss secretes an allelopathic substance called hydroperoxycycloartan through its rhizoids, this substance causes bud death and leaf abscission (Reséndiz-Vega and Sánchez-Trujillo, 2021).

These epiphytes absorb atmospheric moisture for their development, allowing them to survive even in extreme drought conditions and sporadic rainfall (Apodaca and Guerrero, 2019; Montana *et al*., 1997; Flores-Flores *et al*., 2016). They obtain water and nutrients through leaf trichomes (Flores-Palacios, 2017). Among invasive epiphytes, *T. recurvata* shows morphophysiological plasticity in response to radiation availability, as it is found in diverse environments (Borges e Silva *et al*., 2023), and serves as a niche for a variety of microenvironments and arthropod resources, becoming important places for biodiversity (Castañeda *et al*., 2023).

There are few studies related to the effects of ball moss, there is evidence that indicates that these plants are linked to the death of several types of trees including conifers and broadleaf trees, as well as in the vegetation of arid regions such as mesquite (*Prosopis* spp.) and huisache (*Acacia* spp.) (Cortés-Anzures *et al*., 2020; Aguilar-Rodríguez *et al*., 2016; Rodríguez-Robles and Arredondo, 2022). Researchers such as Cabrera *et al*. (1995) and Flores *et al*. (2012) mention that the species *T. recurvata* produces compounds that cause diseases in tree branches. Ball moss is an epiphytic plant that is currently considered a pest (Gómez-Ramírez *et al*., 2023), although it is not parasitic and does not extract nutrients from the host, it competes for light and oxygen from the environment, which hinders photosynthesis, respiration and transpiration of the host tree, weakens the branches and causes the death of hay and various forest species (Sánchez *et al*., 2022). Various investigations have been carried out in relation to the species *T. recurvata* and *T. usneoides*, and some of them indicate that these epiphytes or ball moss turn out to be the appropriate biological indicators to monitor urban and industrial pollution due to their ability to accumulate particles present in the air, as well as their property to retain magnetic particles (Miranda *et al*., 2016; Piazzetta *et al*., 2018; Buitrago *et al*., 2023; Parente *et al*., 2023; Alvarado-Rosales and Saavedra-Romero, 2024). Several studies have determined its use in detecting the presence of atmospheric mercury (Hg), cadmium (Cd), copper (Cu), and lead (Pb) in urban forests (Morera-Gómez *et al*., 2021; Klumpp *et al*., 2023; Lafortezza *et al*., 2023; Wu *et al*., 2023).

The species *T. recurvata* shows remarkable fire resistance due to its high moisture content. Woody plants such as pines, oaks, ash trees, mesquites, and huisaches, among others, are the preferred hosts, as pointed out by Pérez-Noyola (2020). In Peru, it has been observed in fruit trees such as avocado (*Persea americana* Mill), mango (*Mangifera indica* L.), lucuma (*Pouteria lúcuma* L.), citrus fruits (*Citrus* spp.), and molles (*Schinus molle* L.). Fruit trees in full production and advanced stages of their cycle are affected by the presence of ball moss, moss adhered between the branches of the trees, and in percentages of high infestation cause leaf abscission in the hosts, thus observing a significant reduction of leaves, which is frequent in large trees of different ages, causing the death of branches or the entire tree (Castellanos-Vargas *et al*., 2009). Given the wide range of ecological conditions in which *T. recurvata* can thrive, it is considered a eurioic species. This plant can grow both as an epiphytic and epipetric plant, and it is possible to find it in a variety of natural environments, from the canopy of tall trees, through cacti or shrubs less than a meter above the ground, to urban areas where it develops in buildings and cables (Apodaca and Guerrero, 2019).

The Huánuco region, Peru is not immune to the problem of the invasion of *T. recurvata*. Fruit vegetation, forest trees, and shrubs within home gardens, commercial orchards, and agricultural research centers are highly infested and severely affected by *T. recurvata*. In the area of Canchan, which houses among its plots the germplasm bank of citrus (*Citrus* sp.), mango (*Mangifera indica* L.), and forests, the infestation has been severe; preliminary evaluations show conditions in the category of 5 to 6 according to the classification of Hawksworth (1977).

In this study, the objective was to evaluate the application of sodium bicarbonate, copper sulfate, vinegar, yeast, and the combination of these in order to determine their efficacy in the control of *T. recurvata*.

Materials and methods

The research was carried out at the Canchan Research and Experimentation Center, geographically located at coordinates 79° 11' 20" W and 09° 58' 50" S, at an altitude of 2020 meters above sea level. With temperatures ranging from 18.8 to 25 °C, with a minimum of 17 °C and an average temperature of 22 °C. With an average annual rainfall of 281.80 mm, and an average annual relative humidity of 64.32 % (National Meteorology and Hydrology Service of Peru [SENAMHI], 2023). The study used plants of lucuma (*Pouteria Lucuma* L.), citrus (*Citrus limon* L., *Citrus sinensis* L., *Citrus reticulata* L.), and mango (*Mangifera indica* L.) established in the research area. The experimental design consisted of completely randomized blocks with 10 treatments (table 1) and 5 repetitions with two trees each, for a total of 10 plants per treatment and a complete sample of 100 plants distributed in the experimental field.

In each tree, five branches were identified with the presence of ball moss, classified with bands of different colors for identification according to each treatment.

Table 1. Description of treatments.

Key	Treatments	Product (%) / L of water
T1	Sodium bicarbonate	8.60 %
T2	Vinegar	8.20 %
T3	Copper sulfate	1.50 %
T4	Chemical yeast	1.20 %
T5	Vinegar + sodium bicarbonate	8.2 % + 6.4 %
T6	Vinegar + copper sulfate	0.3% + 1.2 %
T7	Copper sulfate + sodium bicarbonate	1% + 4.3 %
T8	Vinegar + chemical yeast	7.5% + 1.2 %
T9	Chemical yeast + copper sulfate	1.2 % + 1 %
T10	No application	

Note. Technical specification: vinegar with an acidic pH (pH=3.0), sodium bicarbonate (pH=8.0), copper sulfate (pH=3.5-4.5, purity 98.8 %), chemical yeast (pH=6.0-6.2).

For the application of the treatments, a high-pressure stationary gasoline-powered sprayer (6.5 HP) was used, with a pressure range of 300-500 psi, a capacity of 10-17 $L.min^{-1}$, a 100-meter hose, 1 rod, and a suction hose with filter. The doses were prepared individually in plastic trays with a capacity of 20 L.

Variables evaluated

Grade of infestation

The Hawksworth procedure was applied (1977).

Grade of damage

A 5-point Likert scale (0-4), as described by Sampieri *et al*. (1991), and adapted to this study (table 2), was applied. The evaluation consisted of observing the texture and color of the epiphytes on each tree and the level of damage they exhibited.

Table 2. Likert scale described by Sampieri *et al*. (1991), adapted by the author.

Grade of damage	Impact	Nature of the epiphyte
0	Without damage	Live epiphytes, well hydrated, with a white-ash hue.
1	Slight damage	Epiphytes with a white-ash hue and brown burns at the tips.
2	Significant damage	Dehydrated and brittle epiphytes, but still attached to the host, with a dark brown hue.
3	Death without abscission	Dead, black, dehydrated, and brittle epiphytes, without abscission.
4	Death with abscission	Dead, black, dehydrated, brittle epiphytes with abscission.

Source: Likert scale (Sampieri *et al*., 1991).

Weight of epiphytes

After collection, the epiphyte samples were transferred to the laboratory, where they were classified according to the treatments under study. Samples were cleaned of impurities that could interfere with weighing, employing fine brushes and gentle compressed air flow to remove residue without damaging structures. The dried epiphytes were weighed on a high-precision analytical balance, and pre-calibrated to ensure the accuracy of the measurements. The weight of each sample was recorded in grams, with an accuracy of up to 0.0001 g. Each sample was placed on the balance pan using fine-tipped laboratory tweezers to minimize human contact and prevent moisture or oil transfers.

Moisture loss

The calculation of this variable was carried out as follows: the green weight was adapted to the average weight of the ball moss of the control treatment, which is 100 % moisture of the ball moss, and the anhydrous or dry weight was called the weight of the treated ball moss (Butrón Hernández, 2014), the formula is PH (%)= (Pv-Po)*100/Pv, where: PH (%) is the percentage of moisture loss, Pv is the green weight and Po the dry weight.

For the variables studied, three evaluations were carried out every fifteen days.

The statistical methodology applied included the analysis of variance (ANOVA) to test the hypotheses, using significance levels of 5 %. The averages that share letters in vertical arrangement indicate that there are no statistically significant differences between treatments, according to Duncan's test (p-value > 0.05). The InfoStat statistical software was used (Di Rienzo *et al*., 2020).

Results and discussion

Grade of infestation

Figure 1 shows that 99 % of the trees, regardless of species, were infested with *T. recurvata*, placing them in grade 4 (high level of infestation). The remaining 1 % was placed in grade 2 (with the first third infested and the second third with mild infestation), according to the classification proposed by Hawksworth (1977). The high level of infestation could be influenced by the environmental conditions favorable for *T. recurvata* in the area under study, as Apodaca and Guerrero (2019) point out, the species could colonize numerous tree plant species in arid zones and inter-Andean valleys.

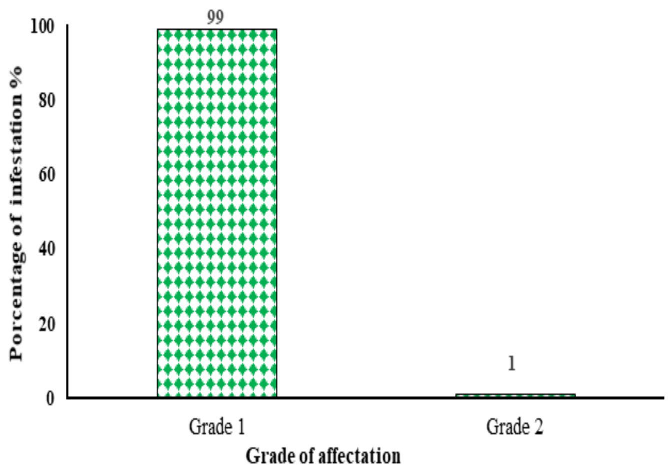

Figure 1. Graphical representation of the grade of infestation in epiphytic plants.

Effect of treatments on epiphytes

Weight

The treatment with sodium bicarbonate showed superior effectiveness compared to the other treatments, as evidenced by the decrease in the weight of *T. recurvata* from 2.2 to 0.26 g in the first and third evaluations, respectively; followed by the vinegar + sodium bicarbonate, copper sulfate + sodium bicarbonate and copper sulfate treatments, with weights of 1.03, 1.19 and 2.24 g, respectively in the third evaluation, the treatments T6 and T8 with statistically similar responses to each other, as well as T2 and T9; in the last position was the treatment T10 (no application) with 3.08 g of *T. recurvata* on average (table 3). These values coincide with the findings of Rodríguez-Robles and Arredondo (2022) who demonstrated the efficacy of non-polluting products such as 5 % acetic acid (vinegar) and 80 $g.L^{-1}$ sodium bicarbonate, applied directly to the epiphyte, achieving death within 10 days. Gómez-Ramírez *et al*. (2023) pointed out the most effective methods to manage *Tillandsia*, highlighting that the combination of sodium bicarbonate in amounts of 1290 g with 15 L of water (equivalent to 86 $g.L^{-1}$ of water) and sodium bicarbonate with 967 g in 15 L of water (equivalent to 64 $g.L^{-1}$ of water) achieved control rates in the tree of 98 % and 95 %, respectively. Velázquez-Cárdenas *et al*. (2021) also obtained similar results when seeking to establish the optimal dose of sodium bicarbonate and chemical yeast for the management of *T. recurvata*.

Table 3. Average weight of *T. recurvata* in the first, second, and third evaluations subjected to various control treatments.

Treatments	1st		2nd		3rd	
	Avg. (g)	Sig. (0.05)	Avg. (g)	Sig. (0.05)	Avg. (g)	Sig. (0.05)
T1	2.2	a	1.39	a	0.26	a
T5	2.31	b	1.78	b	1.03	b
T7	2.37	bc	2.12	c	1.19	c
T3	2.45	cd	2.37	d	2.24	d
T6	2.5	de	2.47	de	2.36	e
T8	2.52	de	2.51	e	2.44	e
T2	2.55	de	2.59	e	2.54	f
T9	2.58	ef	2.57	e	2.54	f
T4	2.68	f	2.84	f	2.94	g
T10	2.95	g	3.06	g	3.08	h

Note. Different letters indicate statistical differences in the columns. Avg.: average Sig.: significance

Moisture

Treatment T1 (sodium bicarbonate) was the most efficient in moisture loss, from 25.62 % in the first evaluation to 91.65 % in the third evaluation, followed by treatment T5 (vinegar + sodium bicarbonate) which showed a gradual increase in moisture loss over time from 21.81 % in the first evaluation to 66.66 % in the third evaluation, followed by treatments T7 and T3 (copper sulfate + sodium bicarbonate and copper sulfate) which caused a moisture loss of 19.83 % and 16.96 % in the first evaluation, respectively, up to 61.35 % and 27.45 %, respectively in the third evaluation; with the last position being treatment T10 (no application) with 0 % moisture loss during the three evaluations (Table 4).

Table 4. Moisture loss of *T. recurvata* in the first, second, and third evaluations subjected to various control treatments.

Treat-ments	1st		2nd		3rd	
	Avg. (%)	Sig. (0.05)	Avg. (%)	Sig. (0.05)	Avg. (%)	Sig. (0.05)
T1	25.62	a	54.56	a	91.65	a
T5	21.81	b	41.74	b	66.66	b
T7	19.83	bc	30.76	c	61.35	c
T3	16.96	cd	22.8	d	27.45	d
T6	15.2	de	19.19	e	23.22	e
T8	14.47	de	18.16	ef	20.9	e
T2	13.82	de	15.9	f	17.57	f
T9	12.44	e	15.47	f	17.35	f
T4	9.24	f	7.26	g	4.67	g
T10	0	g	0	h	0	h

Note. Different letters indicate statistical differences in the columns.

Grade of damage

It was evidenced that treatments T5 (vinegar + sodium carbonate) and T1 (sodium bicarbonate) had the greatest effect on the grade of damage of *T. recurvata*, with effects up to level 1 being evidenced in the first evaluation, representing slight damage in *T. recurvata* of ash-white hue and brown burns. Subsequently, both treatments progressed to level 3 in the third evaluation, with the death of the epiphytic plants without abscission: the epiphytes were totally dehydrated, black, fragile, and brittle. In the background, the treatment T7 (copper sulfate + sodium bicarbonate) stands out, which showed a level 2 (significant damage with dehydrated and fragile areas, but without abscission from the host, and with a dark brown hue) during the second and third evaluation. In contrast, the other treatments showed lower mortality levels of *T. recurvata*, with treatment T2 (vinegar) resulting in level 0 (live, hydrated, ash-white colored ball moss plants) and treatment T10 (control) showing live, hydrated, ash-white colored *T. recurvata* without damage, being the least affected in order of importance (figure 2).

These results are consistent with what was observed by Gómez-Ramírez *et al*. (2023), who applied vinegar and carbonate treatments for the control of *T. recurvata*. They recorded mortality and desiccation of the ball moss in the first two weeks after application, as well as deterioration and decrease in survival during the first two weeks after application with sodium bicarbonate. Meanwhile, Alvarado-Rosales and Saavedra-Romero (2024) when applying sodium bicarbonate to T. *recurvata* showed that it caused dehydration, necrosis, and death of the epiphyte, so they recommend implementing control activities in the months of vegetative development of the epiphyte. In addition, Morera-Gómez *et al*. (2021) demonstrated the efficacy of non-polluting products, such as 5 % acetic acid (vinegar) and 80 g/L^{-1} sodium bicarbonate, applied directly to the epiphyte, achieving death in a short term. Figure 3 shows a photograph of *T. recurvata* with damage grades of 0 and 3.

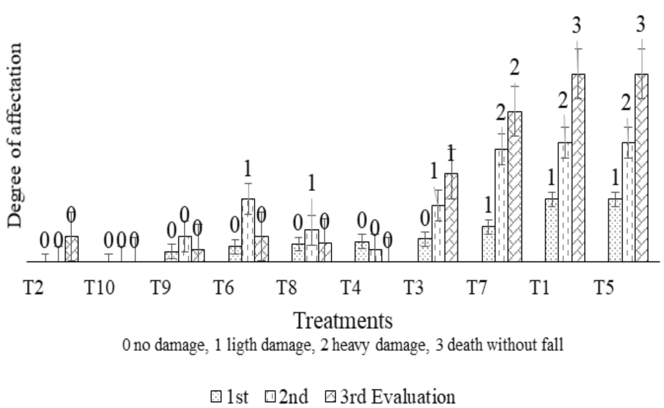

Figure 2. Graphical representation of the grade of damage of *T. recurvata*. T1: sodium bicarbonate; T2: vinegar; T3: copper sulfate; T4: chemical yeast; T5: vinegar + sodium bicarbonate; T6: vinegar + copper sulfate; T7: copper sulfate + sodium bicarbonate; T8: vinegar + chemical yeast; T9: chemical yeast + copper sulfate; T10: No application.

Figure 3. A) Grade of damage 0, B) Damage grade 3, with treatment T5 (sodium bicarbonate + vinegar).

Conclusions

The study concludes that 99 % of the trees presented a high level of infestation (level 4) of *Tillandsia recurvata*. The treatment with sodium bicarbonate was the most effective in reducing the weight of *Tillandsia*, in addition to being the most efficient in dehydration, achieving a moisture loss of 91.65 % in the third evaluation. Finally, the treatments with sodium bicarbonate and its combination with vinegar achieved the highest grade of damage, reaching grade 3 in the third evaluation. This result indicates that these treatments are the most effective in causing the death of *T. recurvata*, recommending their use for the integrated management of this epiphyte in infested trees.

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