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Yellow Nutsedge (*Cyperus esculentus* L.) as an Agricultural Crop in Brazil: Tuber Dormancy Breaking

Márcio Antônio Godoi Junior [1], Rebeca Soares da Silva [1], Rodrigo Nogueira de Sousa [2], Cleide Maria Ferreira Pinto [3], Wellington Souto Ribeiro [1] and Kassio Ferreira Mendes [1,*]

[1] Department of Agronomy, Federal University of Viçosa, Viçosa 36570-900, MG, Brazil; marcio.godoi@ufv.br (M.A.G.J.); rebeca.s.silva@ufv.br (R.S.d.S.); wellington.souto@ufv.br (W.S.R.)
[2] Department of Soil Science, "Luiz de Queiroz" College of Agriculture, University of São Paulo, Piracicaba 05508-030, SP, Brazil; rodrigoagroufv@gmail.com
[3] Brazilian Agricultural Research Corporation, Brasilia 70770-917, DF, Brazil; cleide.pinto@embrapa.br
* Correspondence: kfmendes@ufv.br; Tel.: +55-31-9-9445-0906

Abstract: Yellow nutsedge (*Cyperus esculentus* L.) is cultivated worldwide due to its agricultural and biotechnological potential. In Brazil, it is considered a weed, and we lack studies on its cultivation. Overcoming tuber dormancy is crucial for propagation. This study aimed to assess various dormancy-breaking methods' effects on tubers and initial plant development. The treatments included gibberellic acid immersion, ethylene exposure, purple nutsedge extract immersion, temperature conditioning, scarification, and bud cutting, along with a control. Scarification resulted in the shortest emergence time (0.904 days) and fastest emergence speed (5.092 tubers/day). Plant development was minimally affected by the treatments, with scarification and gibberellic acid (100 mg L^{-1}) resulting in taller plants (1.19–1.23 times higher than the control). The conditioning at 4 °C and 70 °C proved to be less effective in breaking dormancy. Purple nutsedge extract immersion and bud cutting hindered plant growth. Scarification emerged as the most effective dormancy-breaking method. This study provides insights into the cultivation of yellow nutsedge in Brazil, highlighting the effectiveness of scarification in improving tuber germination and the early growth stages of plants.

Keywords: agricultural production; plant biotechnology; scarification; vegetables; weed

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1. Introduction

Cyperus esculentus L. (Cyperaceae: Poales) is a perennial herbaceous monocot plant with an upright, non-branching, glabrous stem, ranging from 20 to 90 cm in height [1]. Also known as "tiger nut", "yellow nutsedge", or "chufa", *C. esculentus* features an underground system characterized by tubers at the ends of rhizomes, which can be short or up to 60 cm long [2]. Despite being considered one of the main weeds [3], "yellow nutsedge" tubers have attracted interest from both the food industry and other global industries due to their nutritional and biochemical components.

In European countries like Spain, *C. esculentus* is known as chufa, and in Valencia, a refreshing, vitamin-rich beverage called "Horchata de Chufas" is produced [4]. According to the recent data from the Consejo Regulador de la Denominación de Origen Chufa de Valencia [5], approximately 3342.6 hectares were dedicated to yellow nutsedge production in Spain in 2021. Other countries, like Nigeria, Australia, and some North American countries, also utilize yellow nutsedge, known as such in these regions as an energy food and in non-food industries [6]. In Africa, yellow nutsedge oil is commercialized, with a composition similar to olive oil, but with greater oxidation stability than other vegetable oils [7]. Yellow nutsedge starch also presents interesting properties for the food and pharmaceutical industries, as its gel texture properties surpass those of corn and sweet potato starches [7]. Additionally, yellow nutsedge has been recognized as a beneficial food, contributing to the prevention of certain heart conditions, thrombosis, and improving

blood circulation, as well as aiding in protection against cancer, due to its high content of soluble glucose [8]. Flour made from yellow nutsedge tubers combined with chickpea flour can serve as a substitute for wheat flour in gluten-restricted diets, contributing to various baking products [9]. Additionally, the tubers can be consumed and marketed fresh, roasted, or cooked, presenting a slightly sweet flavor [4].

Despite its market potential, versatility, and high nutritional value, yellow nutsedge cultivation is limited globally, with few studies focusing on production technology. In Brazil, research on yellow nutsedge primarily addresses its behavior and control as a weed [10,11]. Therefore, there is a need for studies on overcoming tuber dormancy, the main propagation method, to facilitate crop establishment, rapid field growth, and uniform sprouting.

Tuber dormancy in plants refers to a temporary physiological and morphological state where sprouting does not occur, even under ideal conditions [12]. Dormancy is an adaptive characteristic developed by plants to survive environmental adversities and ensure species propagation, particularly among weeds [13]. However, dormancy poses a challenge for cultivated plant production, leading to the development of methods to overcome dormancy in seeds, flower buds, and tubers, among others. Overcoming tuber dormancy is predominantly studied in seed potatoes (*Solanum tuberosum*), employing chemical, hormonal, mechanical, and physical methods [14]. The studies on yellow nutsedge tuber dormancy breaking are outdated [15], and there are no studies addressing dormancy breaking in Brazilian edaphoclimatic conditions, which is essential for its utilization as an agricultural crop in Brazil.

With its global importance in biotechnology and agriculture, yellow nutsedge has to be introduced as a prospective crop in Brazil. There is a study gap in yellow nutsedge cultivation since it has been largely unexplored despite being considered a weed in Brazil. An important part of its spread is tuber dormancy, which calls for efficient management techniques. To disrupt the dormancy of tubers, a number of techniques have been suggested, including immersion in gibberellic acid, exposure to ethylene, scarification, and others. The effectiveness of these methods for cultivating yellow nutsedge in Brazil has not been thoroughly studied. It is important to know the mechanisms involved in dormancy breaking and how they affect the initial development of plants in order to maximize the growth of yellow nutsedge in Brazilian agricultural systems. As evidenced by research conducted by authors such as Huang et al. [16] and Du et al. [17], integrating the insights from remote sensing technology and crop growth models can improve our comprehension of agricultural dynamics and guide management strategies. The development of accurate plant material analysis methods [18] and soil carbon storage analysis [19] offers insightful viewpoints to the study of agricultural systems that may be applied to the growth of yellow nutsedge. By analyzing several dormancy-breaking techniques and their effects on tuber germination and early plant growth, this research seeks to fill in these knowledge gaps and shed light on the potential of yellow nutsedge as a crop in Brazil.

The main objective of this research is to develop and evaluate effective methods for breaking the dormancy of yellow nutsedge tubers, aiming to facilitate crop establishment, rapid field growth, and uniform sprouting. Breaking tuber dormancy is essential to maximize the growth potential of yellow nutsedge in Brazilian agricultural systems and fully explore its value as a crop.

2. Materials and Methods

2.1. Experiment Location

The experiment took place in a greenhouse of the Department of Agronomy at the Federal University of Viçosa (DAA/UFV) at the Agronomy Valley Teaching, Research, and Extension Unit (UEPE), located in Viçosa, MG, Brazil, from April to May 2023. Treatment application was carried out in the Postharvest Physiology Laboratory, and result evaluations were conducted in the Integrated Weed Management Laboratory. All materials used in the experiment were provided by DAA/UFV.

2.2. *Cyperus Esculentus* Tubers

Yellow nutsedge tubers were initially obtained from the Federal University of Maranhão (UFMA), São Luís, MA, Brazil, and cultivated and multiplied in a greenhouse belonging to DAA/UFV. The multiplied tubers were used to generate new plants and were utilized in this experiment. The tubers were planted on 4 April 2023, after all the treatments were applied, in 200-cell polystyrene seed trays, with each cell having a volume of 15 cm^3. The substrate used was MecPlant brand (Telêmaco Borba, PB, Brazil), composed of pine bark, vermiculite, acidity corrector, macronutrients, and a cation exchange capacity (CEC) of 20 $cmol_c$ Kg^{-1}. Irrigation was performed daily via a microsprinkler system, providing approximately 3 mm of water and maintaining adequate moisture levels for cultivation. The tubers for planting were selected based on similar size and shape characteristics.

2.3. Experimental Design and Dormancy-Breaking Treatments

The experimental design employed was a randomized complete block, with 9 treatments and 4 replications, each consisting of 10 tubers (experimental units). Selected yellow nutsedge tubers were randomly allocated for the application of the dormancy-breaking treatments. The studied treatments are described in Table 1.

Table 1. Dormancy-breaking treatments of yellow nutsedge (*Cyperus esculentus*) tubers.

Control (no dormancy-breaking treatment)
Immersion in gibberellic acid (GA) at 10 mg L^{-1}
Immersion in GA at 100 mg L^{-1}
100 µL Ethylene
Immersion in purple nutsedge extract (*Cyperus rotundus*)
Conditioning at 4 °C
Conditioning at 70 °C
Scarification
Bud cutting

In the control treatment, the tubers were planted under natural conditions, without applying any dormancy-breaking treatment. In the gibberellic acid (GA) solution treatment at 10 mg L^{-1}, the replicates were arranged in 4 Petri dishes with tubers immersed in a gibberellic acid solution (Sigma, Merck KGaA, Darmstadt, Germany) at 10 mg L^{-1} for 48 h. In the GA solution treatment at 100 mg L^{-1}, the replicates were arranged in 4 Petri dishes with tubers immersed in gibberellic acid solution at 100 mg L^{-1} for 48 h. In the treatment with 100 µL ethylene, the replicates were placed in 4 open Petri dishes inside a 60 L container, which was hermetically sealed using a glass cover and silicone to apply 6 mL of ethylene (Ruiming Gas) using a syringe. The tubers remained immersed for 48 h. In the treatment with purple nutsedge (*Cyperus rotundus*) extract, approximately 100 g of purple nutsedge tubers collected at UEPE of Agronomy Valley was macerated, added to 200 mL of water, and filtered with a paper towel. The solution was evenly applied to yellow nutsedge tubers placed in Petri dishes, allowing them to immerse for 24 h. In the conditioning treatment at 4 °C, the replicates were placed in 4 open Petri dishes and placed in a cold chamber at a constant temperature of 4 °C (+/−1 °C) for 7 days. On the seventh day, the samples were removed and exposed to room temperature (26 °C) for 4 h before planting. In the conditioning treatment at 70 °C (+/−1 °C), the replicates were placed in 4 beakers and immersed in a water bath with a rotary evaporator (Tecnal, model TE210, Piracicaba, SP, Brazil) for 1 h at a constant temperature of 70 °C. In the bud-cutting treatment, a transverse cut was applied to all the samples of this treatment, dividing the tuber in half. Each part of the cut tuber was planted in different cells in the polystyrene tray, but remained paired. Each pair of tubers (originating from the same tuber) was considered a sample unit. A saw knife was used for cutting. In the mechanical scarification treatment, the tubers from each replicate were scarified around their perimeter, except in the bud region. Eighty-grit construction sandpaper (Famastil) was used for this procedure.

The treatments were applied according to the established schedule to ensure the simultaneous planting of all tubers on the same day.

2.4. Seedling Evaluations

To assess the effectiveness of dormancy-breaking treatments in yellow nutsedge tubers, the following variables were analyzed:

Plant height (from the plant collar to the height of the last fully expanded leaf), leaf number (manually counted), tiller number (manually counted), and dry biomass. Fresh biomass was obtained by weighing the entire plant, including aboveground parts, roots, and tubers, using a precision digital scale (Shimadzu, model AY220, Rosary, Philippines).

Dry biomass was obtained by placing the entire plant, including aboveground parts, roots, and tubers, in an oven at 65 °C (Solab, Piracicaba, SP, Brazil) for approximately 96 h. After removal from the oven, the yellow nutsedge plants were exposed to room temperature (26 °C) for 30 min, and then weighed using an analytical balance. The results are expressed in grams.

The emergence percentage (EP) was determined by visually observing sprouting on the substrate surface. Then, the number of tubers that emerged over 30 days was counted for each of the replicates of their respective treatments. The EP was calculated as the number of emerged tubers (N) divided by the total number of tubers planted (A), according to Equation (1) [20].

$$EP = (N/A)100 \quad (1)$$

The emergence speed index (ESI) was calculated by summing the number of tubers that emerged at time (ni) divided by the time of the test setup (ti) of 30 days, as described in Formula (2) [21]. The result is dimensionless.

$$ESI = \sum (ni/ti) \quad (2)$$

The time mean emergence (TME) was calculated using Formula (3) by Laboriau [22], where 'ni' represents the number of tubers that emerged per day and 'ti' represents the incubation time (30 days). The result is expressed in days.

$$TME = (\sum ni\ ti)/\sum ni) \quad (3)$$

2.5. Statistical Analysis

The experiment data were analyzed using an ANOVA F-test performed with Sisvar software (version 5.6. for windows, Department of Exact Sciences, Federal University of Lavras—UFLA, Lavras, Minas Gerais, Brazil). When significant, the results were subjected to Tukey's test ($p \leq 0.05$) for mean contrasting between different dormancy-breaking treatments, and the data were analyzed in the form of box plots using Origin® software (version 2019b for Windows, OriginLab Corporation, Northampton, MA, USA).

3. Results and Discussion

3.1. Effect of Treatments for Breaking Dormancy in Cyperus esculentus Tubers

In this study, analyses of the tuber emergence percentage (Figure 1), emergence speed index (Figure 2), and mean emergence time (Figure 3) were performed. The results of the applied treatments were compared with the outcome of the control treatment to assess the effect of the treatments on the emergence of yellow nutsedge tubers.

There was interaction among the treatments ($F = 11.010$; $p = 0.0000$) for the germination percentage. No treatment resulting in emergence differed from the emergence percentage of the control (Figure 1). Thus, the application of treatments did not interfere with the tuber emergence percentage. The tubers treated with conditioning at 70 °C did not emerge (Figure 1). One possible explanation for this result is the degradation of meristematic cells in the bud due to exposure to high temperatures for an extended period, although there are no studies explaining the possible cause of this effect in yellow nutsedge tubers.

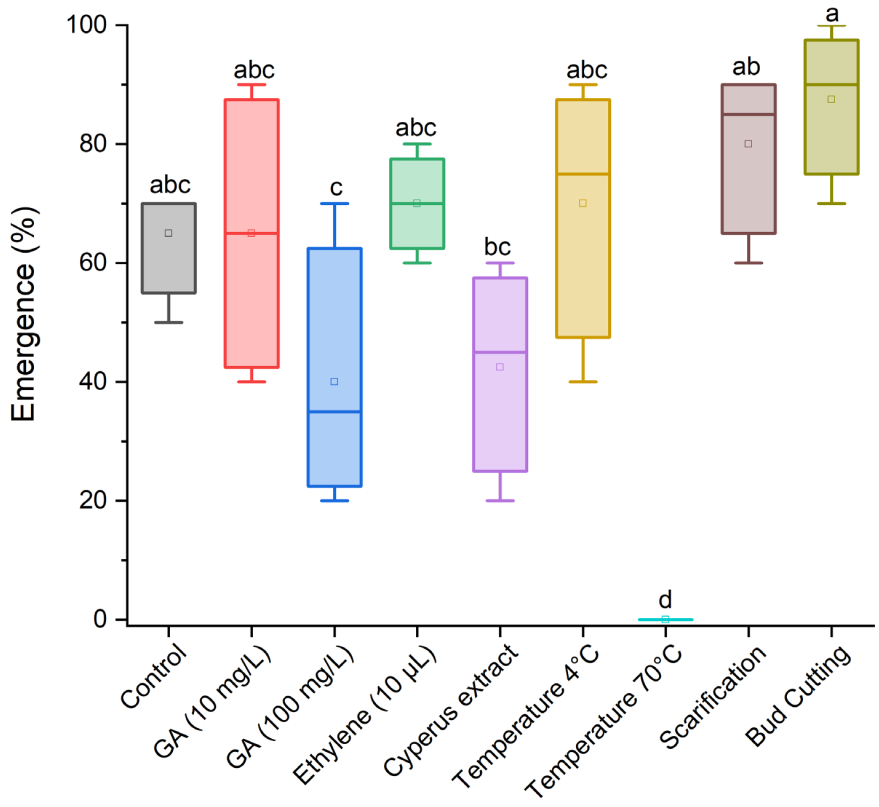

Figure 1. Emergence (%) of yellow nutsedge (*Cyperus esculentus*) tubers up to 30 days after planting under different treatments for breaking dormancy, including immersion in 10 and 100 mg L^{-1} gibberellic acid (GA); immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at 4 °C and 70 °C; scarification; and bud cutting, in addition to a control treatment without any dormancy-overcoming method. Treatments with the same letters on top of each box plot do not differ significantly according to Tukey's test ($p < 0.05$).

A significant difference was also observed between the treatments of bud cutting and scarification and the treatment with GA at 100 mg L^{-1}. A total of 100 mg L^{-1} GA resulted in a worse performance and greater data dispersion compared to scarification and bud cutting (Figure 1). This result may be explained by the high endogenous level of gibberellins already present in the tuber, diminishing the effect of gibberellic acid application [23]. As yellow nutsedge exhibit the staggered emergence of their tubers, it is necessary to analyze the data regarding the time and speed at which each treatment interferes with emergence.

Regarding the variable of the emergence velocity index of yellow nutsedge tubers, there was an interaction among the treatments ($p < 0.05$). The scarification treatment was the only one that differed from the control among the treatments that showed germination (Figure 2). The tubers that were scarified showed a higher number of emerged sprouts per day during the evaluation period, where 50% of the data obtained were above ~1.3 (Figure 2). The bud cutting treatment did not differ from the scarification treatment, and they were the only ones that involved controlled damage to the tuber surface. The abrasion of the tuber surface with sandpaper and the halving of the tubers in the process of scarification and bud cutting, respectively, may have promoted greater tuber imbibition and provided the highest emergence velocity. It was not possible to determine, in this study, whether the scarification and bud cutting processes led to increased concentrations of endogenous growth-promoting hormones, such as auxins, gibberellins, and cytokinins.

Therefore, under field conditions, the scarification treatment, by promoting the faster emergence of planted tubers, reduced the time for crop establishment in the field. Consequently, it reduced the time of weed interference with the crop, favoring competitiveness and the initial development of yellow nutsedge as an agricultural crop over weeds.

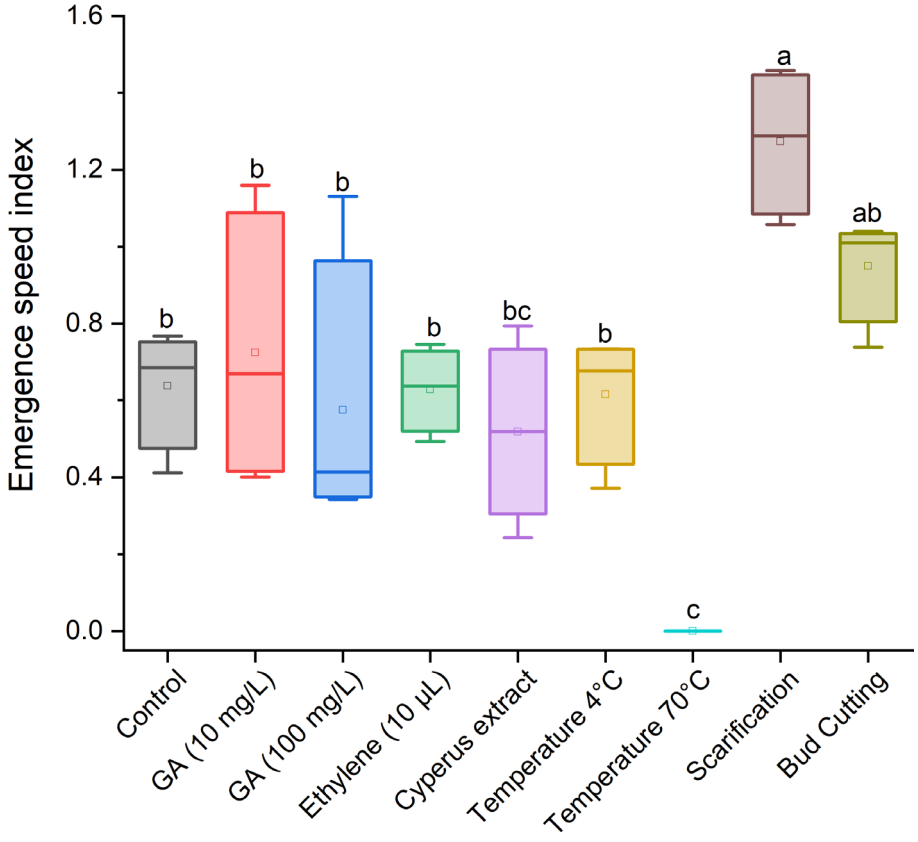

Figure 2. Emergence speed index of yellow nutsedge (*Cyperus esculentus*) tubers up to 30 days after planting under different treatments for dormancy breaking, including immersion in 10 and 100 mg L^{-1} gibberellic acid (GA); immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at temperatures of 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy-overcoming method. Treatments with the same letters at the top of each box plot do not differ significantly according to the Tukey test ($p < 0.05$).

There was interaction among the treatments ($p < 0.05$) for this variable: the average emergence time of yellow nutsedge tubers. The treatments that differed from the control were scarification and immersion in 100 mg L^{-1} GA, both showing the shortest time to emerge their respective numbers of tubers (Figure 3). However, immersion in 100 mg L^{-1} GA showed a low ESI, which was a divergent result (Figure 2). This fact can be explained by the low percentage of tuber emergence under this treatment and the wide dispersion of emergences in the first days after planting. Thus, the few tuber emergences that occurred were dispersed (low ESI) in the initial days of analysis (low TME).

The treatment with immersion in 100 mg L^{-1} GA differed from the treatment with immersion in 10 mg L^{-1} GA only via the analysis of average emergence time. This result applies to the distribution of emergences over the analyzed time, so that the tubers treated with 10 mg L^{-1} GA emerged in a more dispersed manner over time, consequently obtaining a longer average emergence time (Figure 3).

The treatments involving immersion in 10 mg L^{-1} GA for 48 h, 100 µL ethylene, immersion in nut grass extract, conditioning at 4 °C, and bud cutting did not differ from the control in any of the emergence analyses conducted. Therefore, further research could explore varying doses of gibberellic acid, application methods, interaction times, and combination with other compounds, such as ethanol [24]. Additionally, future studies could investigate different temperature ranges from those evaluated in this study and exposure times of yellow nutsedge tubers for dormancy breaking [15].

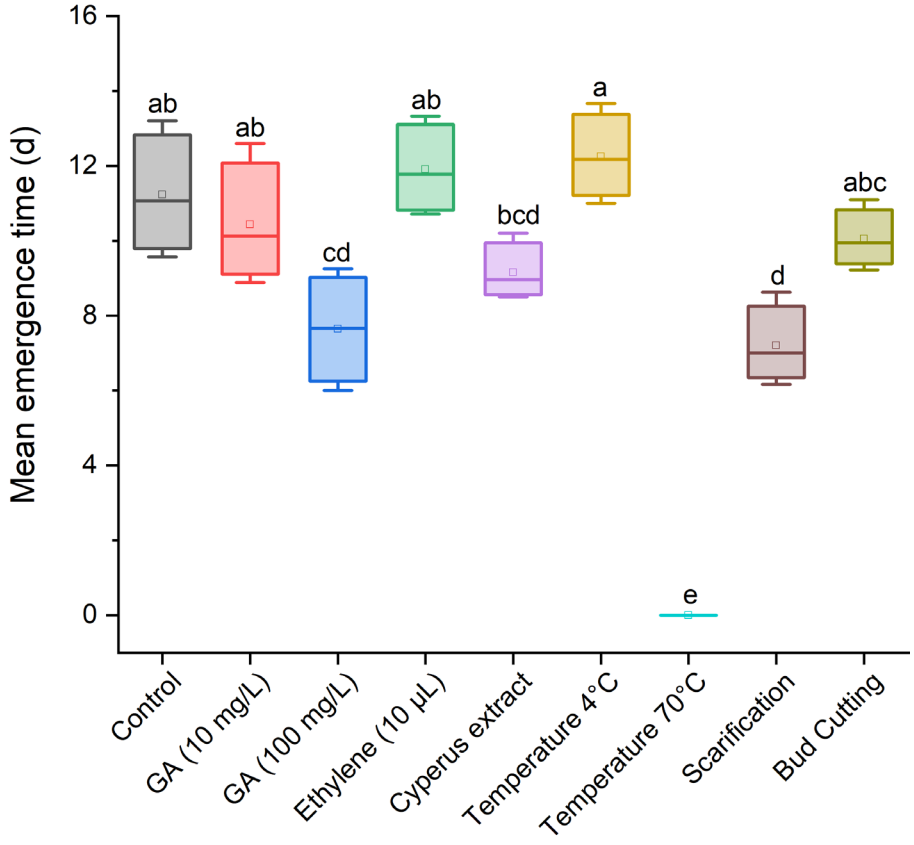

Figure 3. Time mean emergence (days) of yellow nutsedge (*Cyperus esculentus*) tubers up to 30 days after planting under different treatments for dormancy breaking, including immersion in gibberellic acid (GA) at 10 and 100 mg L^{-1}; immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus)*; conditioning at 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy-breaking method. Treatments with the same letters at the top of each box plot do not differ significantly according to Tukey's test ($p < 0.05$).

3.2. Effect of Dormancy-Breaking Treatments on the Initial Development of Cyperus esculentus Plants

There was interaction among the treatments ($p < 0.05$) for the plant height variable. The effect of dormancy-breaking treatments on yellow nutsedge tubers affected the height of the emerged plants (Figure 4). The tubers treated with 100 mg L^{-1} GA and scarification were superior to the control tubers. The concentration of 100 mg L^{-1} gibberellic acid resulted in taller plants compared to those in the treatment with 10 mg L^{-1}. This effect may be attributed to the higher concentration of gibberellic acid, as gibberellins promote leaf and stem elongation by stimulating cell elongation [25]. The treatment involving conditioning at 4 °C negatively impacted the plant height, resulting in smaller plants (Figure 4). The treatments with 10 mg L^{-1} GA, 100 µL ethylene, and bud cutting did not differ from the control. Liu et al. [26] reported, in their study, that the variation in tuber size influences the growth and development of yellow nutsedge plants. According to the authors, tuber size was identified as one of the main factors influencing dormancy breakage.

With respect to the number of leaves of yellow nutsedge, there was interaction among the treatments ($p < 0.05$). No treatment differed from the control, except for the treatment with a temperature of 70 °C, where the tubers did not emerge (Figure 5). Therefore, the treatments did not affect the plant's height. However, it was noted that the treatment with purple nutsedge extract resulted in a higher number of leaves compared to the treatment with 10 mg L^{-1} GA and a temperature of 4 °C. In the treatment with the purple nutsedge extract, approximately 50% of the plants have a minimum of ~10 leaves, although the data dispersion in this treatment is greater when compared to all the other treatments under analysis. In addition to the high number of leaves, the treatment with purple nutsedge

extract also resulted in greater tillering (Figure 6), although it did not differ from the control. There are no studies in the scientific literature that justify this behavior of yellow nutsedge development under exposure to purple nutsedge tuber extract. Conversely, in a study conducted with different rice cultivars, purple nutsedge extract immersion resulted in negative plant development [27].

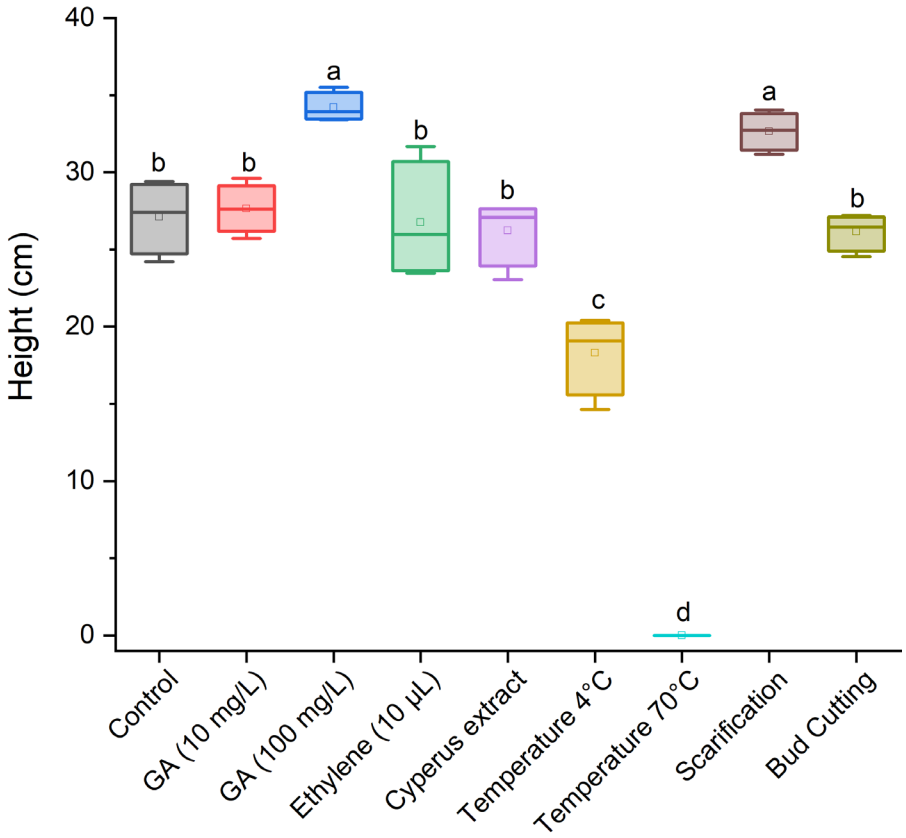

Figure 4. Height (cm) of yellow nutsedge *(Cyperus esculentus)* plants 30 days after planting, under different dormancy-breaking treatments, including immersion in gibberellic acid (GA) at 10 and 100 mg L^{-1}; immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy-breaking method. Treatments with the same letters at the top of each box plot do not differ significantly from each other according to Tukey's test ($p < 0.05$).

Upon analyzing the variable number of tillers, there was interaction among the treatments ($p < 0.05$). It was noted that no treatment differed from the control, but some treatments differed from each other, such as scarification and immersion in 100 mg L^{-1} GA (Figure 6). The tubers subjected to the scarification treatment showed more tillers compared to those immersed in 100 mg L^{-1} GA. Gibberellic acid can induce sprouting in yellow nutsedge only when the tuber buds are not in the more advanced stages of dormancy. In field conditions as a weed, yellow nutsedge induces sprouting when its tubers are injured by scarification or when its buds are cut. Consequently, in vegetable cultivation areas where there is more soil disturbance, there is a higher incidence of *Cyperaceae*. For this reason, systemic herbicides that translocate within the plant via the xylem and phloem are recommended for controlling yellow nutsedge as a weed in order to deplete the energy reserves of its tubers and not just cause senescence of the aerial part, as occurs with contact herbicides.

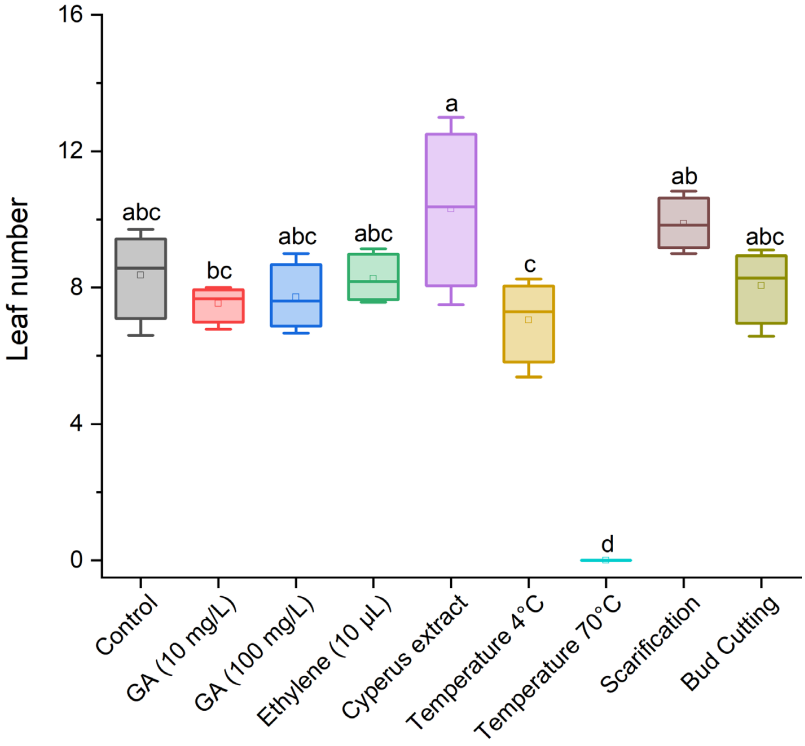

Figure 5. Number of leaves of yellow nutsedge *(Cyperus esculentus)* plants 30 days after planting, under different treatments for dormancy break, including immersion in gibberellic acid (GA) at 10 and 100 mg L^{-1}; immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at temperatures of 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy break method. Treatments with the same letters at the top of each box plot do not differ from each other according to Tukey's test ($p < 0.05$).

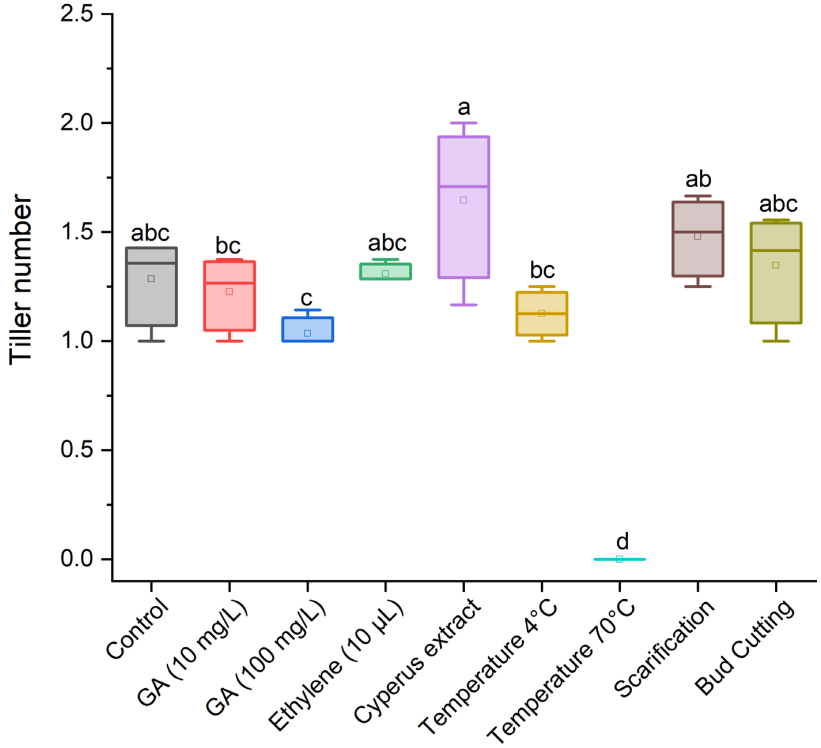

Figure 6. Number of tillers of yellow nutsedge (*Cyperus esculentus*) plants 30 days after planting under different treatments for dormancy breaking, including immersion in gibberellic acid (GA) at 10

and 100 mg L^{-1}; immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at temperatures of 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy-overcoming method. Treatments with the same letters at the top of each box plot do not differ from each other according to Tukey's test ($p < 0.05$).

Upon analyzing the variable of dry biomass, there was interaction among the treatments ($p < 0.05$). The results obtained for dry biomass were better for the scarification treatment, but they did not differ from the control (Figure 7). Compared to the control treatment, only bud cutting showed a difference, with median values that were approximately 1.76 times lower than the dry biomass of the control. This result may be attributed to us planting only half of the tuber, meaning only 50% of its reserves for sprouting were available. The other half of the tuber did not emerge in any of the repetitions in this treatment.

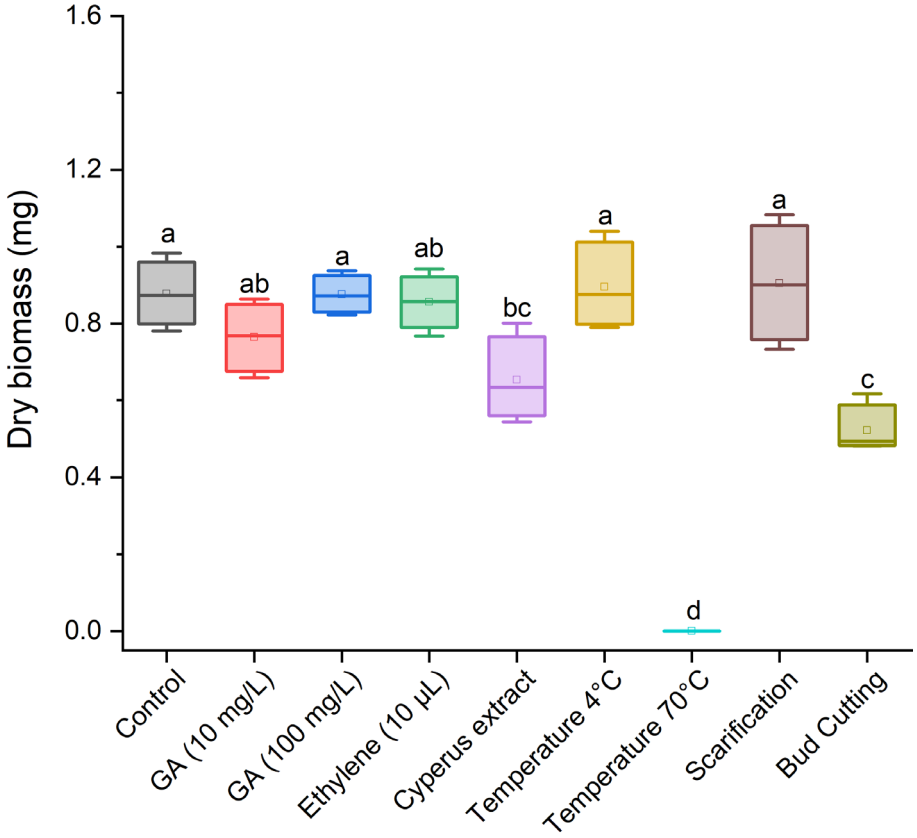

Figure 7. Dry biomass (mg) of yellow nutsedge (*Cyperus esculentus*) plants 30 days after planting under different treatments for dormancy breaking, including immersion in gibberellic acid (GA) at 10 and 100 mg L^{-1}; immersion in 100 µL ethylene; immersion in purple nutsedge extract (*Cyperus rotundus*); conditioning at 4 °C and 70 °C; scarification; and bud cutting, in addition to the control treatment without any dormancy overcoming methods. Treatments with the same letters at the top of each box plot do not differ significantly according to Tukey's test ($p < 0.05$).

According to the Figure 7, it can be observed that the values of dry biomass obtained in yellow nutsedge tubers subjected to conditioning at 4 °C are high, with a maximum value of ~1.03 mg, which does not differ from the scarification treatment, although it shows a lower plant height, number of leaves, and fewer tillers. Additionally, the conditioning treatment at 4 °C shows less data dispersion compared to the scarification treatment.

Some treatments showed tubers at an early stage of tuberization, as can be observed in Figure 8. This non-uniformity in plant development may have influenced the dry biomass results, considering that the effects of dormancy-breaking tests on yellow nutsedge were not evaluated for tuber production in pots or field conditions in this study. In order to

make the study more comprehensive, it is important to conduct planting in field conditions and analyze how tuber production is affected by the different treatments.

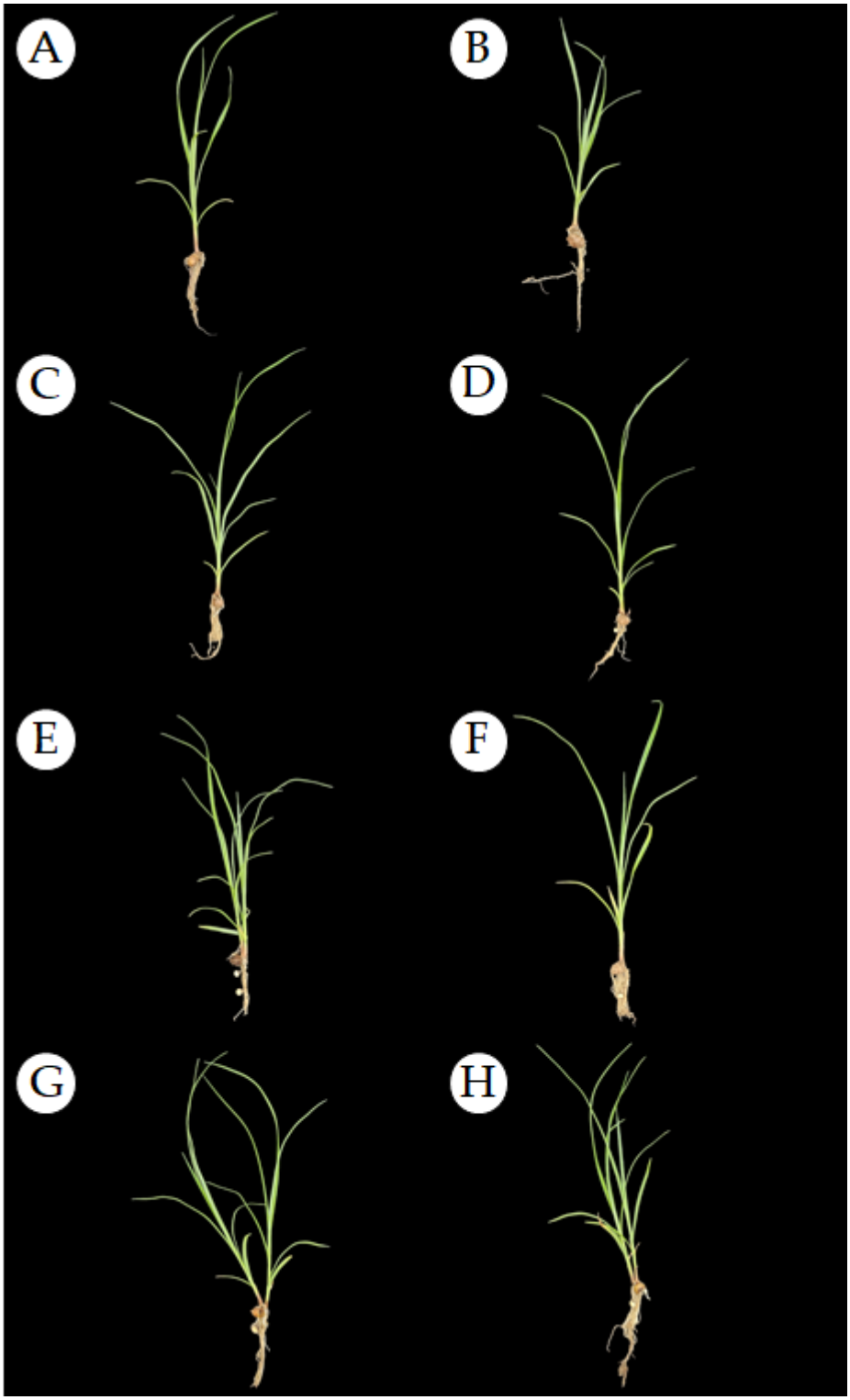

Figure 8. Representative images of yellow nutsedge (*Cyperus esculentus*) plants in each treatment at 30 days after planting for qualitative analysis subjected to the following treatments: (**A**) control without any dormancy-breaking methods; (**B**) 10 mg L^{-1} GA; (**C**) 100 mg L^{-1} GA; (**D**) 100 µL ethylene; (**E**) extract of purple nutsedge (*Cyperus rotundus*); (**F**) a temperature of 4 °C; (**G**) scarification; and (**H**) bud cutting.

4. Conclusions

Under the conditions of this study, none of the dormancy-breaking treatments had a positive impact on the emergence percentage of yellow nutsedge tubers, except for scarification. This treatment resulted in tubers with a higher emergence velocity and a reduced mean emergence time, promoting more uniform and rapid sprouting. In contrast, the other treatments were not effective in overcoming dormancy, which are similar to the control. Therefore, scarification stands out as a more accessible and practical option for rural producers compared to the other techniques. Additionally, the use of scarification also accelerates crop establishment in the field, favoring their growth over that of the weed community.

Author Contributions: The individual contributions of the authors in this scientific work were essential for its execution and preparation. M.A.G.J. and R.S.d.S. were responsible for carrying out the project, conducting the experiments, and drafting the manuscript. R.N.d.S. performed the analysis and interpretation of the data using software. W.S.R. contributed to defining the methodology and conducting the experimental treatments. C.M.F.P. played an important role in the conception and acquisition of funding for the project. K.F.M. played a fundamental role as the supervisor, reviewer, editor, and validator of the manuscript in terms of intellectual content, as well as contributing to the discussion and decision making regarding the results and final conclusions. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data analyzed in this study are available upon request to the corresponding author.

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