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Induction of rooting in fig tree cuttings due to the use of coconut water as a root growth promoter

Indução de enraizamento em estacas de figueira em razão da utilização de água de coco como promotora de crescimento radicular

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Highlights

Coconut water provides good rooting results for ‘Turco’ fig.
Different rooting agents elicit distinct effects on ‘Turco’ fig.
Coconut water exhibits viability for rooting fig accessions.

Abstract

Ficus carica L. is compatible with Brazil’s soil and climatic conditions, making the country its largest producer in Latin America. Brazilian fig cultivation utilizes cutting propagation for plant multiplication; the Roxo de Valinhos cultivar is the most widely cultivated. Other fig accessions also have market value, such as the Turco cultivar, which is generally used as a rootstock. Vigorous seedlings are necessary for good fruit production; they can be obtained using growth regulators, such as indolebutyric acid (IBA; the most commonly used regulator in fruit production), to enhance rhizogenesis. However, natural products, such as coconut water (rich in auxins), are also viable for this purpose. In this study, we aimed to determine the most advantageous rooting stimulator for ‘Turco’ fig cuttings and verify whether the product used is

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related to the type of fig accession. Two consecutive experiments were conducted using a randomized block design. The first experiment included three treatments: powdered IBA; coconut water; and IBA solution at 6,000 mg L^{-1}, conducted in the municipality of Dracena, SP; this was conducted to identify the best rooting agent to be used in the second experiment. The second experiment included eight treatments: accession 33; accession 34; accession 35; accession 47; accession 40; accession 41; accession 42; and accession 45, conducted in the municipality of Ilha Solteira, SP. Both experiments were conducted in a greenhouse with intermittent misting for 40 days. At the end of each experiment, the percentage of rooting, number of sprouts, length of the longest sprout, fresh and dry mass of the shoots and roots, and relative growth rate (RGR; obtained by measuring the cuttings' sprouts at 10-day intervals) were analyzed. Data were subjected to statistical analysis in SISVAR using Tukey's test at $p \leq 0.05$; RGR data were adjusted using second-order polynomial regressions. The first experiment demonstrated that the use of coconut water resulted in 100% root growth for 'Turco' fig. The second experiment demonstrated that the utilization of coconut water depends on fig accession; results differ for each treatment, with accession 45 ('Turco') obtaining the best results. The other accessions obtained promising results, except for accession 33 and 41. Hence, coconut water is considered an effective rooting stimulator for fig cultivation.
Key words: Cuttings. *Ficus carica* L. Rooting biostimulators.

Resumo

Ficus carica L. é compatível com o solo e as condições climáticas do Brasil, tornando o país o maior produtor da América Latina. O cultivo no Brasil utiliza a propagação por estaquia para a multiplicação das plantas; a cultivar Roxo de Valinhos é a mais cultivada. Outras cultivares de figo também têm valor de mercado, como Turco, geralmente utilizada como porta-enxerto. Mudas vigorosas são necessárias para boa produção de frutos; elas podem ser obtidas utilizando reguladores de crescimento, como o ácido indolbutírico (AIB; regulador mais utilizado na fruticultura), estimulador de rizogênese. No entanto, produtos naturais, como a água de coco (rica em auxinas), também são viáveis para esse fim. Neste estudo, objetivamos determinar o estimulador de enraizamento mais vantajoso para estacas de figo 'Turco' e verificar se o produto utilizado está relacionado ao tipo de cultivar de figo. Dois experimentos consecutivos foram conduzidos utilizando um delineamento em blocos casualizados. O primeiro experimento incluiu três tratamentos: AIB em pó; água de coco; e solução de AIB a 6.000 mg L^{-1}, conduzida no município de Dracena, SP; este foi realizado para identificar o melhor agente de enraizamento a ser utilizado no segundo experimento. O segundo experimento incluiu oito tratamentos: acesso 33; acesso 34; acesso 35; acesso 47; acesso 40; acesso 41; acesso 42; e acesso 45, conduzido no município de Ilha Solteira, SP. Ambos foram conduzidos em casa de vegetação com nebulização intermitente por 40 dias. Ao final de cada experimento, foram analisados a porcentagem de enraizamento, número de brotos, comprimento do broto mais longo, massa fresca e seca da parte aérea e das raízes, e taxa de crescimento relativo (TCR; obtida pela medição dos brotos das estacas em intervalos de 10 dias). Os dados foram submetidos à análise estatística no SISVAR usando o teste de Tukey com $p \leq 0,05$; os dados de TCR foram ajustados usando regressões polinomiais de segunda ordem. O primeiro experimento demonstrou que o uso de água de coco resultou 100% de crescimento radicular para cultivar Turco. O segundo experimento demonstrou que a utilização de água de coco depende da cultivar de figueira; os

resultados diferem para cada tratamento, com acesso 45 ('Turco') obtendo os melhores resultados. As outras cultivares obtiveram resultados promissores, exceto acesso 33 e 41. Portanto, a água de coco é considerada um bioestimulador de enraizamento eficaz para o cultivo de figueiras.
Palavras-chave: Bioestimuladores de enraizamento. Estaquia. *Ficus carica* L.

Introduction

The fig tree, *Ficus carica* L., is a species belonging to the Moraceae family. Its inflorescence is called a syconium, which produces fig fruits. The plant offers landscaping value in the form of ornamental use and fruit growing (Ming et al., 2011); it also contributes to the food sector with its fresh or processed fruits and to the industrial sector with its leaves and latex. Brazil is the largest fig producer in Latin America, with an approximate production of 21,000 tons, according to the Instituto Brasileiro de Geografia e Estatística [IBGE] (2023). In Brazil, fig cultivation is growing in popularity owing to the plant's adaptability with the country's edaphoclimatic conditions. The southeast region is the largest producer, led by the state of São Paulo mainly with the Roxo de Valinhos cultivar (Targino, 2023); fig cultivation also extends to semi-arid regions (Moura et al., 2023).

Apart from its compatibility with Brazil's climate, the Roxo de Valinho cultivar has an advantage in that its fruits do not require pollination for formation (Pio & Chagas, 2011) and presenting good commercial acceptance owing to its flavor and pinkish appearance. However, the widespread use of a single cultivar in Brazil has led to phytosanitary issues (mainly in the roots) that increase production costs, as reported by Mattos et al. (2024). Hence, using other cultivars as rootstocks for Roxo de Valinhos is necessary to diversify the orchards.

'Turco' fig (F. carica) is the most widely produced and marketed fig worldwide. This cultivar belongs to the Smyrna group and is characterized by fruits with increased sweetness and an extended shelf life after harvest (Figueiredo, 2017). Its pollination is carried out by the fig wasp (Blastophaga psenes), an insect not found in Brazil; this absence hinders fig fruit production in the country because manual pollination increases production costs. The viability of 'Turco' fig in Brazil is related to its use as a rootstock, mainly for 'Roxo de Valinhos', as suggested by Silva (2010). 'Turco' fig presents good root development and increased resistance, whereas 'Roxo de Valinhos' fruits offer high commercial value, presenting viable cultivation in the northwest of the state of São Paulo, according to Rodrigues et al. (2019).

In Brazil, fig reproduction occurs asexually by cutting propagation; the technique maintains the desirable characteristics of the mother plant and the target cultivar (Felipe & Ribeiro, 2024) and produces uniform seedlings. To meet both the Brazilian and international markets' needs for the production of quality fruit, seedlings with good productive performance in the field need to be obtained. Root formation is crucial in cuttings; to optimize the process, phytohormones, such as exogenously applied auxins, are used to promote cell elongation and rhizogenesis (Canales & Phelipe, 2018).

The use of auxins, such as the synthetic auxin indolebutyric acid (IBA), is common in fruit growing (Taiz & Zeiger, 2017). Through the exogenous application of IBA, either at the base of the cutting or in solution, the plant absorbs a compound that acts similarly to indoleacetic acid (IAA). Practices using alternative auxin-containing compounds, such as the use of coconut water on cuttings through immersion to stimulate rhizogenesis, are also becoming popular in fruit growing (Rajan & Sing, 2021).

Aside from amino acids and nutrients, the water present in the fruit of Cocos nucifera possesses a significant amount of auxins, gibberellins, and carbohydrates, (Malla et al., 2023; Paulino et al., 2021). These compounds are essential for the early development of cuttings (Aguayo & Quintana, 2020); because they are readily available via a sustainable approach, their use is ideal for both small- and large-scale production, making them a more viable alternative than artificial rooting inducers (Meilawati & Purwiyanti, 2020). According to Rajan and Singh (2021), the use of natural compounds, such as coconut water, is advantageous because it reduces the use of plant growth regulators and can result in an improved rooting quality of fruit cuttings.

Hence, in this study, we aimed to identify the most promising rooting biostimulator for 'Turco' fig trees and investigate whether the use of the compound with the best results is related to different fig accessions used in cutting propagation.

Materials and Methods

This study involved two consecutive experiments, the first was conducted at the Faculdade de Ciências e Tecnologias FCAT/UNESP, Dracena Campus, SP in August 2024; the second was conducted at the Faculdade de Engenharia de Ilha Solteira FEIS/UNESP, Ilha Solteira Campus, SP in October 2024. According to Köppen, both municipalities have an Aw climate (tropical with dry winters). Experiments were conducted in a greenhouse with acrylic walls, a Fan&Pad system (forced ventilation and expanded clay walls), and an intermittent misting system. In the first experiment, different rooting inducers were evaluated for 'Turco' fig (F. carica) cuttings to select the product with the best rooting results to be used in the second experiment, which will be done on different fig accessions. Fig tree cuttings were obtained from the FCAT Fig Germplasm Bank in July 2024. The cuttings were cut at an angle after pruning and collecting the lignified parts (approximately 15 cm long with about five buds, without leaves). Before the installation of each experiment, the cuttings were treated with the fungicide Ridomil® (3 g L^{-1}), being completely immersed for 20 min and air-dried, and subsequently planted at a depth of 4 cm. The use of 'Turco' fig is based on its good performance in the conditions of northwestern São Paulo, where it exhibits good agronomic characteristics, as pointed out by Rodrigues et al. (2019), being viable for use as a rootstock.

The first experiment was conducted in randomized blocks consisting of three treatments and ten repetitions using 'Turco' fig cuttings. The three treatments include application of IBA powder; application of coconut water; and application of an IBA solution (diluted in deionized water at 6,000 mg L^{-1}). For the IBA treatments, Power® Rooting Agent (6,000 mg L^{-1}) was used; the coconut water was obtained directly from the fruit, and the soluble solids content was determined before its use (4° Brix). Parts of the cuttings from treatment coconut water and application of an IBA solution that were covered with substrate were subsequently submerged in the solution for 10 min. The cuttings were planted in 290 cm^3 tubes filled with vermiculite, each of which was an experimental plot, being placed on metal benches 5 cm apart. Irrigation was carried out by intermittent misting (five times a day, for 20 min, at 4 h intervals, using 1.8 L h^{-1} water). Forty days after planting (DAP), the percentage of rooting (PR), number of shoots (NS), length of the longest shoot (SL, cm), and the fresh and dry mass of aerial parts (FAM and DAM) and roots (g; FRM and DRM) were evaluated. Cuttings with developed roots were considered to have rooted.

After conducting the first experiment, we found that coconut water was responsible for rooting 100% of the cuttings, obtaining the highest PR. Hence, it was used as a rhizogenesis stimulator in the second experiment, which was conducted in randomized blocks consisting of eight treatments and ten repetitions: accession 33; accession 34; accession 35; accession 47; accession 40; accession 41; accession 42; and accession 45 ('Turco' fig). All treatments, except accession 45 ('Turco'), were characterized as accessions belonging to the Germplasm Bank of UNESP/FCAT. Coconut water, in which the cuttings were partially immersed for 10 min, was obtained directly from the fruit with a 5° Brix. Cuttings from different accessions were planted in 290 cm^3 tubes filled with a 3:1 ratio of Carolina Soil® substrate (composed of peat, vermiculite, and NPK) and vermiculite in order to obtain seedlings for field planting. Each cutting represented an experimental plot, being placed on metal benches 5 cm apart. Irrigation was performed by intermittent misting (five times a day, for 20 min, at 4 h intervals) to maintain ideal moisture in the cuttings. Forty DAP, the PR, NS, and length of the longest shoot (cm) were evaluated.

In the experiments, the PR was obtained by calculating the ratio of planted cuttings to rooted cuttings. The NS was obtained by counting the shoots present on each of the cuttings, taking the average per treatment; the buds that underwent differentiation were considered as shoots. The length of the longest shoot was obtained using a graduated ruler (cm), whereas the FAM and FRM were obtained by weighing on an analytical balance (g); the DAM and DRM were obtained by weighing on an analytical balance (g) after the material was dried for 72 h at 64 °C in a forced-air oven.

The relative growth rate (RGR) was obtained by measuring the development of cutting shoots at 10-day intervals and was calculated using an adaptation of Benincasa's formula (Benincasa, 2003): RGR = $(\ln Pn - \ln P_{n-1})/(T_n - T_{n-1})$, where lnPn is the accumulated dry biomass up to evaluation n, $\ln P_{n-1}$ is the accumulated dry biomass up to evaluation n^{-1}, Tn is the number of days after emergence at the time of evaluation n, and T_{n-1} is the number of days after emergence at the time of evaluation n^{-1}.

The data obtained in both experiments underwent the Shapiro-Wilk normality test and were subjected to analysis of variance using the F-test ($p \leq 0.05$); if significant, they were subjected to the Tukey test ($p \leq 0.05$) in SISVAR (Ferreira, 2014). Percentage values were transformed $\sqrt{(x + 0.5)}$ to level the coefficient of variation data. The RGR regressions were performed using second-order polynomials.

Results and Discussion

The data obtained from the first experiment (Table 1) indicated that there was no significant difference in the NS, shoot length (SL), FAM and DAM, or FRM; only the DRM exhibited a difference. The diluted IBA presented the best results for those aspects; however, as the results in Figure 1 suggests, it is found that coconut water was responsible for rooting 100% of the 'Turco' fig cuttings, unlike the treatments using IBA, which only reached a PR of 70%. As discussed by Machado and Zamarian (2020), this result can be explained by the presence of auxins and mineral salts in the compound. In another study, Uyoh et al. (2016) also observed a higher PR of 100% by using coconut water than by using IBA in Indian yam, corroborating the data from the present study. Luna et al. (2025) obtained results similar to those of this study by using IBA on fig tree cuttings; in their study, a PR of close to 50% was observed.

Table 1
'Turco' fig cuttings subjected to different rooting agents, in Dracena, SP

Source of variation	NS	SL (cm)	FAM (g)	FRM (g)	DAM (g)	DRM (g)[1]
Treatments	Mean square					
	2.03^{NS}	3.63^{NS}	0.50^{NS}	0.22^{NS}	0.03^{NS}	0.42*
IBA powder	2.7	4.9	2.490	1.269	0.475	0.758b
Coconut Water	2.3	5.6	2.045	1.091	0.384	0.745b
diluted IBA	3.2	6.1	2.302	1.384	0.376	0.928a
CV%	113.73	87.51	81.29	97.18	78.87	18.75
Average	2.7333	5.533	2.279	1.248	0.412	0.81

*Significant; ^{NS} Not significant according to Tukey's test at 5% probability. NS: number of shoots; SL: length of the longest shoot; FAM: fresh mass of the aerial; FRM: fresh mass of the roots; DAM: dry mass of the aerial; DRM: dry mass of the roots. [1] Transformed data: Square root of Y + 0.5 - SQRT (Y + 0.5)

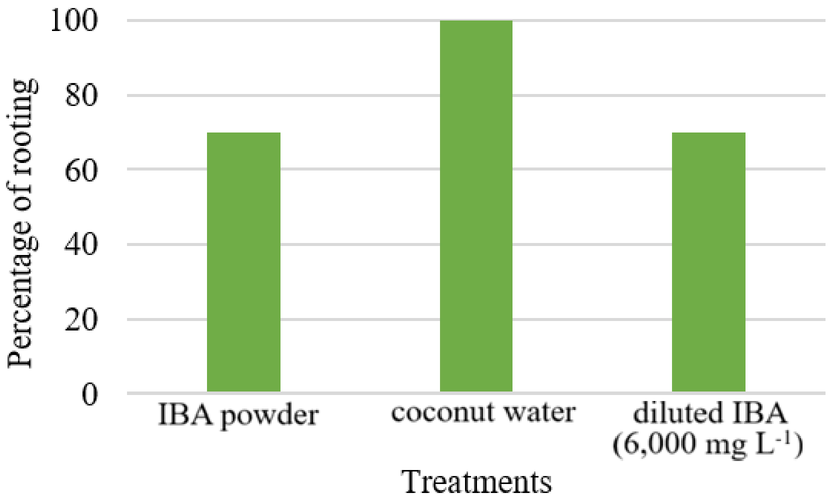

Figure 1. Percentage of rooting of 'Turco' fig tree cuttings in the first experiment using different rooting agents. Conducted in Dracena, SP, Brazil.

The use of coconut water presents different results depending on the cultivar in which it is employed, as found by Meilawati and Purwiyanti (2020), who concluded that the use of coconut water as a rooting agent does not improve plant height and development in *Piper* sp. Conversely, Abshahi et al. (2024) observed that in *Juniperus sabina* L., the use of 100% coconut water without dilution did not obtain results as promising as when it is diluted. In the present study, the use of 100% coconut water without dilution resulted in the rooting of all cuttings.

Because the rooting rate of fig tree cuttings was increased by coconut water, it can be inferred that their survival rate in the field may have also been improved, as supported by Rajan et al. (2023), who observed an improved survival rate of cuttings when using coconut water in grapevine cultivation.

The results of our study are corroborated by the studies done by Tofanelli and Santos (2020) and Hofstaetter et al. (2010), where they found IBA to be responsible for rooting approximately 70% of fig cuttings at doses above 500 mg L^{-1} and increase their root mass by approximately 35% at doses of 2,000 mg L^{-1}. Apart from phytohormones, rooting factor is also related to the reserves contained in the cuttings. In the present study, a PR of 70% was obtained by using 6,000 mg L^{-1} of IBA; however, when half the dose was used (3,000 mg L^{-1}), Paula et al. (2009) found that F. carica plants did not respond to rooting, which was contrary to the data that we obtained. This discrepancy may be justified by the difference in immersion time, product concentration, fig tree accessions, or even the commercial product used.

The NS was higher when using IBA than when using coconut water, which can be explained by the accelerated interaction of the product with the cuttings, increased rhizogenesis, and the improved transport of carbohydrate compounds in the cuttings. In an experiment using 'Roxo de Valinhos' and IBA, Ohland et al. (2009) observed a 27% increase in rooting, which improved the survival rate of the plants, similar to the present study. The improved association of the IBA compound with the cuttings accelerates root development; however, unlike coconut water, the synthetic compound does not contain elements other than auxin.

The high PR obtained by using coconut water can be explained by the compound's composition; it is rich in auxins, gibberellins, and nutrients (Malla et al., 2023), making it viable for use in 'Turco' figs. Although the number of shoots was slightly lower than that in the IBA treatments, the viability of the cuttings was much increased in the field owing to complete rooting. Initially, the development of the cuttings occurred through the use of the reserves found in coconut water, which aids the emergence of shoots and roots; as the days passed, the new roots began to absorb nutrients and water from the substrate, developing the cuttings.

In the second experiment (Table 2), it can be observed that treatment accession 45 ('Turco' fig) obtained increased values for PR and NS; this increase did not occur to SL. 'Turco' fig exhibited a 72% superiority to the treatment, with the lowest PR being observed in treatment accession 33. Accessions 45 and 40 exhibited the highest PR and NS values, whereas accession 41 exhibited the lowest NS and SL values. Through the application of coconut water in different fig accessions, it can be seen that there was a distinct behavior for each treatment. Different rooting stimulators elicit different responses, interfering with the percentage of live and rooted cuttings; in the process, accessions are distinguished by their rhizogenic potential. This explanation was suggested by the studies done by Ferraz et al. (2018) and Bisi et al. (2016), which corroborate the findings of the present study.

Table 2
Cuttings of different accessions of fig trees subjected to coconut water as a rooting agent, in Ilha Solteira, SP

Source of variation	PR (%)	NS	SL (cm)
Accession	Mean square		
	10.95*	66.27*	22.61*
33	10.61 b	4.75 bc	6.2 ab
34	55.55 ab	3.25 c	9.5 a
35	30.88 ab	4.50 c	5.0 ab
47	39.58 ab	2.75 c	7.6 b
40	58.75 ab	10.00 ab	6.8 ab
41	32.14 ab	2.25 c	0.5 c
42	52.08 ab	6.00 bc	7.3 b
45	82.61 a	14.00 a	6.2 ab
CV%	23.29[1]	38.87	50.52
Média	42.27	5.94	6.14

*Significant, NS not significant according to Tukey's test at 5% probability. [1] Values transformed by the equation $\sqrt{(x + 0.5)}$.
PR: percentage of rooting; NS: number of shoots; SL: length of the longest shoot

The use of coconut water obtained promising results for the rooting of certain fig tree accessions. Mamani (2024) observed a PR of approximately 65%, similar to the PR rates found for different cuttings in the same crop (Table 2). Additionally, as observed in the aforementioned study, the response to coconut water was related to the submersion time of the cuttings in the product.

In the present study, the best rooting value for fig was recorded in accession 45 ('Turco'), with a PR of close to 83%. Veliz (2021) found PR values close to 90% for *Polylepis incana*, as did Sousa et al. (2022), who observed that the application of coconut water as a rooting agent increased the PR and the number of leaves in *Dracaena reflexa* Lam.; these findings corroborate the results of the present study. Natural rooting agents have become viable alternatives for various crops. As observed in the present study and in a study carried out by Medina (2022) on *Sambucus nigra* L., coconut water induced excellent rooting, with the root growth response starting on the fifteenth day after application.

In Figure 2, the RGR of the cuttings from the second experiment exhibited a decrease between the first and second points of the curve and a significant increase for most accessions between the second and third points of the curve. This behavior was based on the use of the cuttings' own reserves in the first days after the experiment was set up; from the second point onwards, growth increased owing to the emergence of roots.

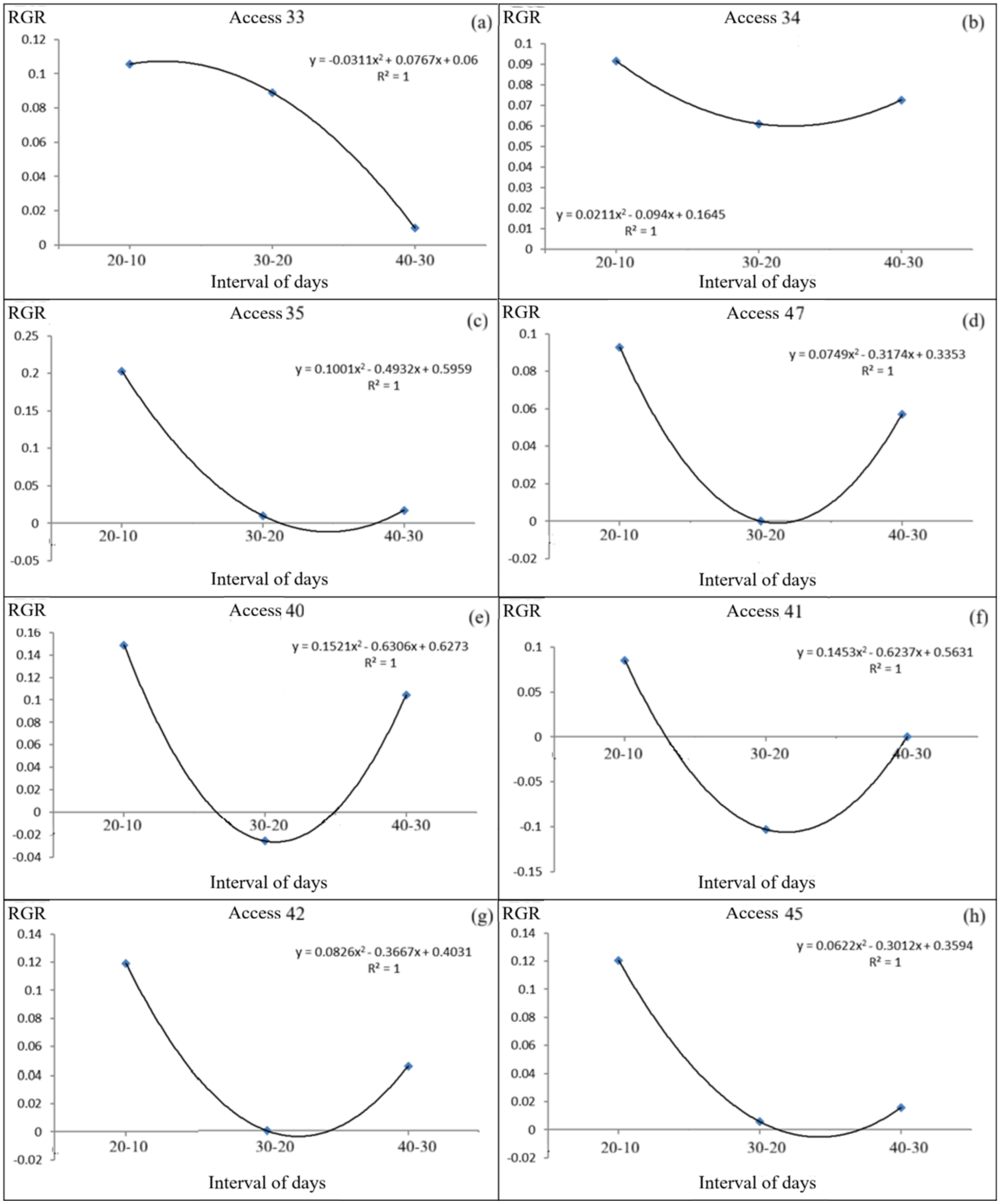

Figure 2. Relative growth rate of the second experiment after application of coconut water to different accessions of fig tree cuttings.
(a) accession 33; (b) accession 34; (c) accession 35; (d) accession 47; (e) accession 40; (f) accession 41; (g) accession 42; (h) accession 45.

The regression models for the eight different accessions (Figure 2) exhibit similar behavior between different accessions; the use of different fig accessions presents different responses to the application of plant growth regulators (Bisi et al., 2016). Figure 2(a), referring to accession 33, relates with the PR data (Table 2) for this treatment with a value of 10.61%, being the only one that differs significantly from the others. The graph shows that RGR remained between the first two points, followed by a drop in development, which indicates no rooting and death of the cuttings, suggesting that coconut water is an unviable rooting agent for this fig accession. Accession 34 (Figure 2[b]) exhibited a different RGR behavior from the others by not demonstrating a large drop in RGR between the first and second points, maintaining growth, and obtaining the highest SL values because of the stable RGR, which assisted in the full development of the fig cutting. Accessions 35 and 45 (Figures 2[c] and 2[h], respectively) exhibited similar RGR behavior, with an initial decrease and a brief recovery up to the third point of the curve. Accession 45 obtained the best NS and PR values for the use of coconut water, which suggests a potential for improving crop development in the field for the future. For accessions 47 and 42 (Figures 2(d) and 2(g), respectively), a similar RGR behavior was also observed, with an increase in development from the second to the third point of the curve, although there was no significant difference in PR. Accessions 40 and 41 (Figures 2(e) and 2(f), respectively) exhibited a negative RGR up to the second point and recovery in development up to the third point; accession 41 achieved better results in all evaluations compared with accession 40.

Of the eight accessions evaluated, 'Turco' fig (accession 45) obtained the most promising results, unlike accessions 33 and 41, which did not obtain satisfactory results when coconut water was used as the rooting agent. Other accessions exhibited satisfactory development for PR, NS, and SL, aligning with results from other experiments that used common rooting agents such as IBA.

Conclusions

Coconut water is a viable rooting stimulator for 'Turco' fig cuttings, with results superior to those obtained using IBA. 'Turco' fig obtained the most promising results among the various fig accessions; the product used was related to the accession. Coconut water is a viable rooting promoter for fig cuttings.

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