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Impact of Ash Waste Material on Morphological Traits of Kurrajong (*Brachychiton populneus* Schott.) and Scots Pine (*Pinus sylvestris* L.) Seedlings

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This study aimed to investigate the effects of ash utilization on the morphological characteristics of Kurrajong (*Brachychiton populneus* Schott.) and Scots pine (*Pinus sylvestris* L.) seedlings. The appropriate handling and use of waste materials is a critical issue in promoting environmental sustainability. Therefore, it is essential to explore alternative waste management methodologies, such as studying the impact of ash on plant growth. In this research, we applied various types of growing media and ash to Kurrajong and Scots pine seedlings. We evaluated the morphological attributes of the seedlings using parameters such as seedling height, root collar diameter, fresh and dry weight of stem and root, Dickson quality index, and sturdiness quotient. The seedlings in the control group and those subjected to different ash treatments exhibited significant differences at a 99.9% confidence level. The results indicated that ash utilization positively influenced the morphological attributes of Kurrajong and Scots pine seedlings. Moreover, the application of ash seemed to have a beneficial effect on seedling length, root collar diameter, and seedling weight. This research introduces an innovative waste management strategy by evaluating the impact of ash on plant growth, thereby highlighting the potential use of waste materials as alternative growing media.
Keywords: Fly ash, kurrajong, nursery, scots pine, seedling, zero waste

INTRODUCTION

The sustainable use of environmental resources and the effective management of waste materials are emerging as critical issues in the contemporary world (Halkos and Petrou, 2016). The disposal of waste materials, which originate from various activities such as industrial operations, energy generation, and agricultural practices, can lead to the degradation of natural ecosystems and a decrease in biodiversity (Bolou *et al.,* 2021; Raven and Wagner, 2021). Therefore, it is necessary to utilize and recycle waste materials effectively to achieve environmental sustainability.

Ash, a byproduct resulting from various industrial processes, is considered a form of waste material (Assi *et al.,* 2020; Rajeshkumar *et al.,* 2021; Thomas *et al.,* 2021). However, ash holds significant potential as a valuable natural resource that can be utilized while also mitigating adverse environmental impacts. In this context, the use of ash as a potential growth medium for plant breeding activities can provide a solution to the waste management problem and offer a new resource for the plant breeding sector.

Research consistently indicates that coal and wood ashes, byproducts of wood and coal combustion, contain nutrients beneficial for plant growth. He *et al.* (2017) discovered that coal fly ash can enhance essential element and selenium supply in plants, particularly when applied at or below a 5% rate. Similarly, Pärn *et al.* (2010) and Lazdiņa *et al.* (2017) both underscored wood ash's potential as a mineral fertilizer. Pärn *et al.* (2010) highlighted its rich plant nutrient content, while Lazdiņa *et al.* (2017) showcased its positive influence on tree growth and vitality. Ohno and Erich (1990) further supported these findings, illustrating how wood ash application can modify soil pH and increase plant-available nutrient levels. Collectively, these studies suggest that coal and wood ashes can benefit plant growth when used appropriately.

Coal and wood ashes serve as sources of macronutrients, promoting balanced plant growth by supplying essential elements for plant development. Antonkiewicz *et al.* (2020) found that co-application of ash and municipal sewage sludge improved plant productivity and nutrient recycling. Similarly, Romanowska-Duda *et al.* (2020) demonstrated the potential of sorghum ash as a supplement for cultivating aquatic macrophytes, leading to increased plant biomass. However, cautioned about the potential toxic effects of wood ash residue on plant growth, stressing the importance of concentration and environmental context. Finally, Lazdiņa *et al.* (2017)

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emphasized the positive impact of wood ash fertilizers on the growth and vitality of forest plantations.

Ash can play a crucial role in neutralizing soil acidity, benefiting specific plant species, and enhancing soil fertility by increasing the availability of vital nutrients such as phosphorus, potassium, calcium, and magnesium. Wood ash, a byproduct of various biomass combustion processes, has shown promising benefits in forestry and agriculture. It can help neutralize soil acidity, enhance nutrient availability, and stimulate microbial activity (Scheepers and du Toit, 2016). Additionally, when combined with charcoal, wood ash can reduce phosphorus fixation in acidic soils, thus improving P availability and crop productivity (Johan *et al.,* 2021). Various types of biomass ashes, including wood ash, have been found to raise soil pH, electrical conductivity, and dehydrogenase activity while also increasing the extractability of certain nutrients (Quirantes *et al.,* 2016). However, the effectiveness of wood ash in alleviating soil acidity and enhancing nutrient availability may vary depending on its source and chemical properties (Shi *et al.,* 2017).

Kurrajong or also known as bottle tree *(Brachychiton populneus* Schott.) belong to *Brachychiton* genus of *Malvaceae* family, and Scots pine *(Pinus sylvestris* L.) are prominent tree species found across diverse ecosystems, valued for their adaptability and ecosystem services. . The species which were exotic have been used as individual trees in forestry and landscape planning in the region. However, effect of the waste ashes which environmental friendly material has not been investigated detail on producing and morphology of the species. Despite their significance, few studies have explored the impact of ash waste material on the morphology of Kurrajong and Scots pine seedlings (Ots *et al.,* 2017; Jansone *et al.,* 2020).

This study aimed to investigate changes in the morphological attributes of Kurrajong and Scots pine seedlings resulting from ash utilization as a waste material extracted ashes from woody branches and fly, and biochar without properties of chemical analysis. The effects of ash on seedling development parameters, including fresh and dry weight of roots and stems, Dickson quality index (DQI), and sturdiness quotient (SQ), were examined. The findings of this study can provide scientific insights into the potential application of ash in the plant breeding industry. Furthermore, the outcomes of this research hold significant scientific value, contributing to advancements in waste management strategies, the sustainability of the plant breeding sector, and environmental impact mitigation. Moreover, this study lays the groundwork for assessing the response of various plant species, such as Kurrajong and Scots pine, to ash utilization or potential, thereby expanding our understanding of the broader implications and potential applications of ash across different plant species.

MATERIALS AND METHODS

***Nursery characteristics*:** The study was carried out at the Pos-Kıcak Forest Nursery, which is part of the Adana Regional Directorate of Forestry. The nursery, situated between 35°12'45" east longitude and 37°34'40" north latitude, is located in the Aladag district of Adana and has an elevation of 980 m above sea level, with a general southeast-facing view. The soil type of the nursery was reddish brown Mediterranean soils at P^H 5-6.

***Seed source*:** The study utilized seeds of Scots pine from Kars Sarıkamıs (40°18'22"N, 42°36'03"E, 2,330 m elevation) and Kurrajong from Adana Çukurova (37°03'29" N, 35°21'16"E, 136 m elevation).

***Ash preparation*:** Red pine ash (RPA) and oak ash (OA), obtained by burning specimens collected from the waste branches, were used in the study. Biochar (BA) was produced by burning standard biochar, while fly ash (FA) was sourced from the thermal power plant in Soma, Manisa. Seedlings in the control (C) group were tended to routinely in the nursery. The ashes used in the study were ground to smaller sizes in a ball mill, and all ashes, whether supplied or obtained through incineration, were sieved to a maximum grain size of 0.1 mm to prepare them for use.

***Preparations before planting*:** In the study, two types of seedlings (bare-root and container seedlings) from two different species *(Pinus sylvestris* and *Brachychiton populneus*) were divided into five treatment groups (RPA, OA, BA, FA, and C). Each treatment group chosen randomly consisted of 40 seedlings, resulting in a total number of 800 seedlings used in the experiment. During nursery operations, which included soil cultivation and land preparation, tube filling operations were performed for container seedlings. Ash was incorporated into the tube filling process at a ratio of 1:4 by volume as a pilot trial. For bare-root seedlings, ash was mixed into the planting pads at a ratio of 1:4 by volume, and the mixture was applied 20 cm from the top of the soil. Seven planting strips were prepared for Scots pine and five for Kurrajong on a planting pad measuring 2 m × 120 cm. Before sowing, the seeds underwent sterilization using hydrogen peroxide (H_2O_2). Sowing took place on March 23 of 2022, and the seedlings were harvested in November of the same year. The nursery practices were routine that irrigation one time per two weeks without fertilization.

***Characteristics of seedlings*:** Measurements of seedling height (SH) and root collar diameter (RCD) were taken with an accuracy of 1 mm and 0.01 mm, respectively, using a ruler and electronic caliper. Stem fresh weight (SFW) and root fresh weight (RFW) were determined using a precision balance (~0.001 g). Root dry weight (RDW) and stem dry weight (SDW) were obtained by drying the seedlings in an oven at 105°C for 24 h before weighing, with a precision of 0.001 g DQI calculated using the formula provided by

Dickson *et al.* (1960). Additionally, the SQ was determined using the SH/RCD ratio.

$$\text{Dickson Quality Index} = \frac{\text{Seedling Dry Weight(g)}}{\frac{\text{Seedling Height(cm)}}{\text{Root Collar Diameter(mm)}} + \frac{\text{Stem Dry Weight(g)}}{\text{Root Dry Weight (g)}}} \quad (1)$$

***Data analysis*:** The collected data from the measurements were analyzed using the SPSS software package (SPSS, 22). In addition to computing basic statistical values, an analysis of variance was conducted to compare the seedling types and treatments in terms of the investigated characteristics.

$$Y_{ijk} = \mu + b_i + p_j + bp_{ij} + e_{ijk} \quad (2)$$

Where Y_{ijk}; i^{th}. seedling type of j^{th}. treatment of k^{th} individual, μ; the overall mean, b_i; the effect of seedling type i, p_j; the effect of treatment j, $bp_{ij;}$ seedling type x treatment interaction, e_{ijk} = environmental error.

The obtained data were evaluated using the SPSS statistical package program. The phenotypic relationships between the two characters were estimated using the Pearson correlation coefficient with the assistance of a specific equation (Sokal and Rohlf, 1995).

$$r_P = \frac{\sum xy}{\sqrt{\sum x^2 \sum y^2}} \quad (3)$$

In the equation;

r_P: phenotypic correlation coefficient,

$\sum xy$: sum of the factors of characters' x and y,

$\sum x^2$, $\sum y^2$: the phenotypic variances of the characters.

RESULTS

Measurements and calculations were performed on the seedlings produced by the study conducted in the Kıcak forest nursery. The values of RCD, SH, SFW, RFW, SDW, RDW, DQI, and SQ were determined. Table 1 shows the relationship between RCD and SH, showing the distribution of bare-root and container seedlings of Scots pine and Kurrajong according to the applied treatments.

Upon the conclusion of the initial growth period, a correlation analysis was conducted to determine the relationship between the characteristics RCD, SH, SFW, RFW, SDW, RDW, DQI, and SQ, irrespective of the seed source, seedling type, and treatments (Fig. 1). Scots pine seedlings exhibited significant ($p < 0.01$) positive ($0.141 \leq r \leq 0.955$) and negative ($0.141 \leq r \leq 0.578$) relationships among the aforementioned parameters. Moreover, Kurrajong seedlings demonstrated significant ($p < 0.01$) positive ($0.149 \leq r \leq 0.962$) and negative ($0.166 \leq r \leq 0.648$) relationships among these parameters. Specifically, Scots pine displayed a significant positive ($r \leq 0.955$) relationship between RDW and DQI at the $p < 0.01$ level. Additionally, in Kurrajong, a significant ($p < 0.01$) positive relationship ($r \leq 0.962$) was observed between SDW and SFW (Fig. 1). So, it could be said that the treatments had positive impact on the characters.

Table 1. Duncan test results for Kurrajong and Scots pine seedling treatments. SH-seedling height, RCD-root collar diameter, SFW-stem fresh weight, RFW-root fresh weight, SDW-stem dry weight, RDW-root dry weight, DQI-Dickson quality index, SQ-sturdiness quotient, C-control, RPA-red pine ash, OA-oak ash, BA-biochar ash, FA-fly ash. *Same letters in columns for species indicate similar groups ($p < 0.05$).

Species	Seedling Type	Treatments	RCD (mm)	SH (cm)	SFW (g)	RFW (g)	SDW (g)	RDW (g)	DQI	SQ
Kurrajong	Bare Root	C	2.64^{d}*	9.24^{c}	1.77^{e}	11.71^{c}	0.69^{d}	6.31^{bcd}	2.36^{b}	2.97^{b}
		RPA	3.03^{cd}	10.15^{c}	2.02^{e}	12.63^{c}	0.69^{d}	7.41^{c}	2.38^{b}	3.41^{a}
		BA	2.95^{d}	10.16^{c}	1.84^{e}	11.60^{c}	0.66^{d}	6.72^{bc}	2.06^{bc}	3.47^{a}
		OA	2.89^{d}	9.83^{c}	1.84^{e}	11.66^{c}	0.64^{d}	6.29^{bcd}	1.97^{bc}	3.47^{a}
		FA	2.75^{d}	9.41^{c}	1.74^{e}	11.16^{c}	0.70^{d}	5.28^{bcd}	1.71^{bc}	3.48^{a}
	Container Seedlings	C	3.65^{b}	10.36^{c}	2.95^{de}	19.11^{b}	1.11^{c}	4.07^{d}	1.59^{c}	2.87^{b}
		RPA	3.87^{b}	14.54^{a}	5.69^{ba}	31.47^{a}	2.18^{a}	11.46^{a}	3.40^{a}	3.78^{a}
		BA	3.74^{b}	12.75^{b}	4.12^{cd}	21.88^{b}	1.50^{b}	4.62^{cd}	1.58^{c}	3.54^{a}
		OA	4.28^{a}	12.05^{b}	4.60^{bc}	27.85^{a}	1.76^{b}	5.35^{bcd}	2.13^{bc}	2.85^{b}
		FA	3.80^{b}	14.16^{a}	6.30^{a}	30.44^{a}	2.09^{a}	10.42^{a}	3.22^{a}	3.75^{a}
Scots pine	Bare Root	C	1.52^{bc}	5.97^{cde}	0.68^{cde}	0.62^{e}	0.25^{bcd}	0.15^{d}	0.08^{e}	4.14^{b}
		RPA	1.75^{a}	6.54^{b}	1.03^{a}	0.95^{bcd}	0.32^{ab}	0.20^{cd}	0.10^{cde}	3.76^{bc}
		BA	1.76^{a}	6.39^{bc}	0.83^{bcd}	0.81^{cde}	0.28^{abc}	0.20^{cd}	0.10^{cde}	3.84^{bc}
		OA	1.85^{a}	5.79^{cde}	0.91^{ab}	0.93^{cde}	0.29^{abc}	0.22^{cd}	0.12^{a-d}	3.21^{d}
		FA	1.77^{a}	7.37^{a}	0.93^{ab}	0.67^{de}	0.33^{a}	0.17^{d}	0.08^{de}	4.27^{ab}
	Container Seedlings	C	1.75^{a}	6.12^{bcd}	0.85^{abc}	1.41^{a}	0.30^{abc}	0.32^{a}	0.14^{a}	3.60^{cd}
		RPA	1.34^{a}	5.84^{cde}	0.59^{e}	0.99^{bc}	0.20^{d}	0.21^{cd}	0.08^{de}	4.70^{a}
		BA	1.47^{bc}	5.40^{e}	0.64^{de}	1.17^{ab}	0.25^{cd}	0.31^{ba}	0.13^{abc}	4.07^{bc}
		OA	1.66^{ab}	6.16^{bcd}	0.72^{cde}	1.32^{a}	0.26^{a-d}	0.35^{a}	0.14^{ab}	3.85^{bc}
		FA	1.51^{bc}	5.61^{de}	0.62^{e}	0.88^{cde}	0.24^{cd}	0.25^{bc}	0.11^{b-e}	3.88^{bc}

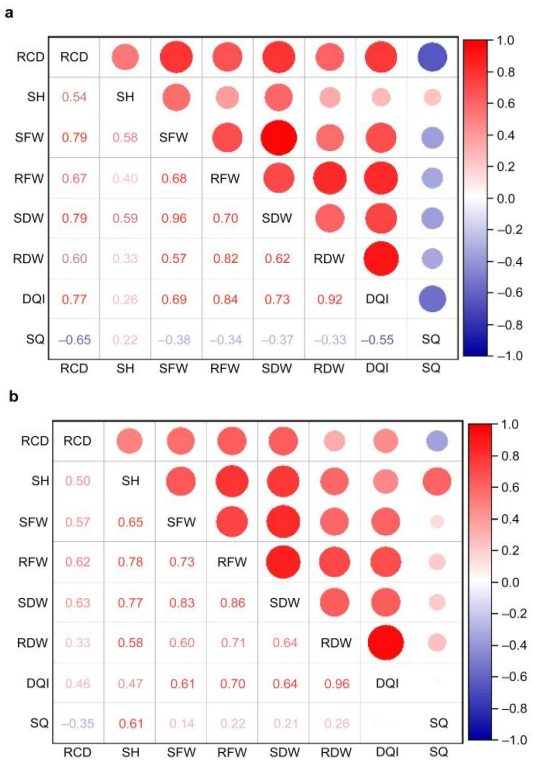


Figure 1. Correlation analysis results for morphological traits: a) Kurrajong seedlings, b) Scots pine seedlings. RCD-root collar diameter, SFW-stem fresh weight, RFW-root fresh weight, SDW-stem dry weight, RDW-root dry weight, DQI-Dickson quality index, and SQ-sturdiness quotient. A significant ($p < 0.01$) positive relationship was found between seedling characteristics.

Analysis of variance revealed significant differences between seedling types and treatments at a 99.9% confidence level for all morphological traits examined in both species.

To determine the grouping of treatments applied to the seedlings based on species, the Duncan test was utilized for evaluating the morphological traits. The outcomes of the test are presented in Table 1.

For the RCD trait, the Duncan multiple range test results showed the formation of four different groups in Kurrajong and three different groups in Scots pine. In Kurrajong, the lowest value of 2.64 was observed in the first homogeneous group, represented by the bare-root control C, while the highest value of 4.28 was recorded for the container seedling OA which formed a class alone. Similarly, in Scots pine, the lowest value of 1.47 was grouped with container seedlings BA in the first homogeneous group, while the highest value of 1.85 was in the last homogeneous group, represented by bare-root OA.

According to the results of the Duncan test for the SH trait, three different groups were formed among the Japanese population. The lowest value was observed in the bare rooted control C (9.24) within the first homogeneous group, while the highest value was noted in the container seedlings treated with RPA (14.54). In terms of seedling length in Scots pine, five different groups were formed. The lowest value was found in the container seedlings treated with OA (5.40), which formed a homogeneous group on its own. In Scots pine, the highest value was observed in the last group alone, with the bare-root FA (7.37) application.

As per the results of the Duncan test for the SFW characteristic, five distinct groups were formed in Kurrajong. The lowest value was found in the first homogeneous group with bare-root FA (1.74), and the highest value was in the last group alone with container seedlings treated with FA (6.30). In terms of SFW in Scots pine, five different groups were formed. The lowest value was in the first homogeneous group with the application of tubed RPA (0.59), and the highest value was in the last group alone with the application of bare-root RPA (1.03).

According to the results of the Duncan test for the RFW trait, Kurrajong was divided into three distinct groups. The lowest value was observed in the first homogeneous group of bare-root FA (11.16), and the highest value was observed in the last homogeneous group of container seedlings treated with RPA (31.47). In terms of RFW in Scots pine, five different groups were formed. The lowest value was observed in the bare-root control C (0.62) treatment, which formed a homogeneous group on its own, and the highest value was observed in the container seedlings control C (1.41) treatment, which was in the last homogeneous group.

According to the results of the Duncan test for the SDW characteristic, four distinct groups were formed in Kurrajong. The lowest value was observed in the first homogeneous group of bare-root OA (0.64), and the highest value was observed in the last homogeneous group of container seedlings treated with RPA (2.18). In terms of SDW in Scots pine, four different groups were formed. The lowest value was observed in the first group with the tubed RPA (0.20) treatment, and the highest value was observed in the last group with the bare-root FA (0.33) treatment. Additionally, in Scots pine, the tubed OA (0.26) application was included in all groups.

According to the results of the Duncan test for the RDW trait, four distinct groups were formed in Kurrajong. The lowest value was observed in the first group with the tubed control C (0.64), which formed a class on its own, and the highest value was observed in the last homogeneous group with the tubed RPA (11.46) treatment. In Scots pine, four different groups were formed. The lowest value was observed in the first group with the bare-root control C (0.15) treatment, and the highest value was observed in the last homogeneous group with the container seedlings treated with OA (0.35).

According to the results of the Duncan test for the DQI trait, three distinct groups were formed in Kurrajong. The lowest value was observed in the first homogeneous group with the biochar ash BA (1.58) treatment, and the highest value was observed in the last homogeneous group with the RPA (3.40) treatment. In terms of DQI in Scots pine, five different groups were formed. The lowest value was observed in the bare-root control C (0.08) treatment in the first homogeneous group, and the highest values were observed in the container seedlings treated with OA and tubed control C (0.14) treatments.

According to the results of the Duncan test for the SQ trait, two distinct groups were formed in Kurrajong. The lowest value was observed in the first homogeneous group with the application of container seedlings treated with OA (2.85), and the highest value was observed in the last homogeneous group with the application of container seedlings treated with RPA (3.78). In terms of SQ in Scots pine, four different groups were formed. The lowest value of bare-root OA (3.21) treatment alone formed a homogeneous group, and the highest value was in the last group with container seedlings treated with RPA (4.70) treatment.

A principal component analysis (PCA) was conducted to assess how the application influenced the morphological characteristics of seedlings. PCA analysis was used to determine the correlations between different groups. The cumulative contributions of the first two principal components, PC1 and PC2, for each species were as follows: For Kurrajong, PC1 accounted for 70.53% of the variation, and PC2 accounted for 24.10%, with a total cumulative variation of 94.63% as shown in Figure 2. The RCD coefficients of PC1 were 0.34 and of PC2 were −0.42 (Table 2).

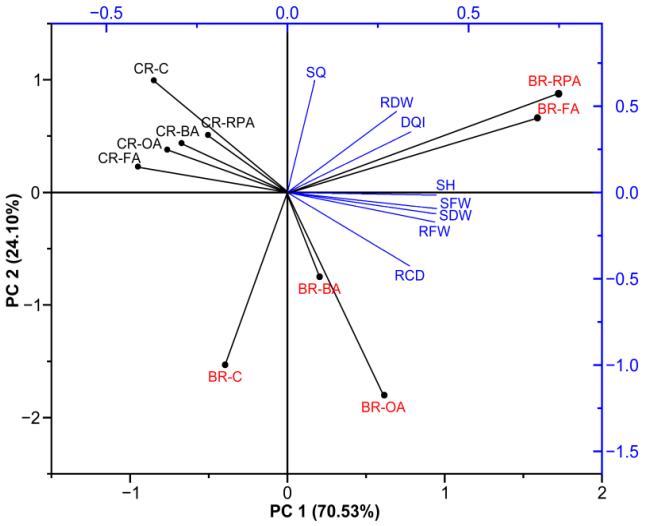


Figure 2. Result of principal component analysis (PCA) for Kurrajong: PCA score plot showing the relationships between eight morphological traits and treatments of Kurrajong seedlings. BR-bare-root, CR-container root, SH-seedling height, RCD-root collar diameter, SFW-stem fresh weight, RFW-root fresh weight, SDW-stem dry weight, RDW-Root dry weight, DQI-Dickson quality index, SQ-sturdiness quotient, C-control, RPA-red pine ash, OA-oak ash, BA-biochar ash, FA-fly ash.

Table 2. Eigenvalues of the correlation matrix for Kurrajong.

Component No.	Eigenvalue	Percentage of variance	Cumulative	Coefficients of PC1	Coefficients of PC2
PC1	5.64	70.53%	70.53%	0.34	−0.42
PC2	1.93	24.10%	94.63%	0.41	−0.01
PC3	0.37	4.59%	99.22%	0.41	−0.09
PC4	0.04	0.50%	99.73%	0.41	−0.17
PC5	0.01	0.17%	99.89%	0.41	−0.12
PC6	0.00	0.09%	99.98%	0.30	0.47
PC7	0.00	0.01%	100.00%	0.34	0.35
PC8	0.00	0.00%	100.00%	0.07	0.65

Note: PC1-RCD, PC2-SH, PC3-SFW, PC4-RFW, PC5-SDW, PC6-RDW, PC7-DQI, PC8-SQ

Table 3. Eigenvalues of the correlation matrix for Scots pine.

Component No.	Eigenvalue	Percentage of Variance	Cumulative	Coefficients of PC1	Coefficients of PC2
PC1	3.68	45.97%	45.97%	0.48	0.18
PC2	3.25	40.65%	86.61%	0.40	−0.19
PC3	0.80	9.99%	96.61%	0.50	0.06
PC4	0.15	1.99%	98.60%	−0.14	0.48
PC5	0.09	1.10%	99.70%	0.50	0.09
PC6	0.01	0.17%	99.88%	−0.18	0.49
PC7	0.01	0.11%	99.99%	−0.05	0.55
PC8	0.00	0.01%	100.00%	−0.25	−0.38

Note: PC1-RCD, PC2-SH, PC3-SFW, PC4-RFW, PC5-SDW, PC6-RDW, PC7-DQI, PC8-SQ

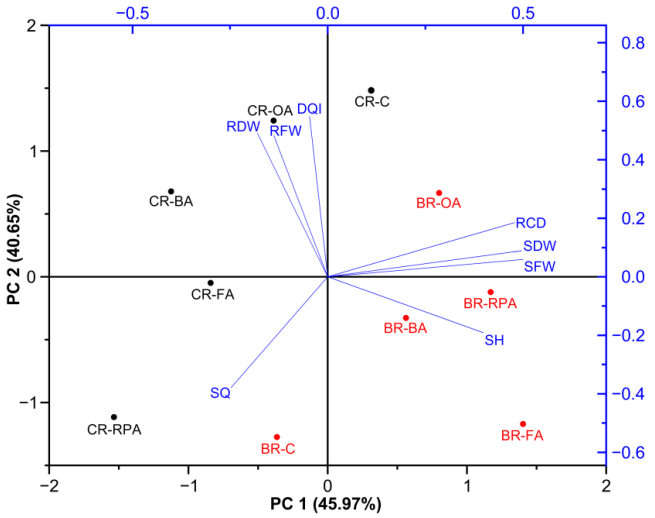


Figure 3. Result of principal component analysis (PCA) for Scots pine: PCA score plot showing the relationships between eight morphological traits and treatments of Scots pine seedlings. BR-bare-root, CR-container root, SH-seedling height, RCD-root collar diameter, SFW-stem fresh weight, RFW-root fresh weight, SDW-stem dry weight, RDW-root dry weight, DQI-Dickson quality index, SQ-sturdiness quotient, C-control, RPA-red pine ash, OA-oak ash, BA-biochar ash, FA-fly ash.

For Scots pine, PC1 explained 45.97% of the variation, while PC2 explained 40.65%, resulting in a cumulative variation of 86.61%, as indicated in Figure 3. The RCD coefficients of PC1 were 0.48 and of PC2 were 0.18 (Table 3).

DISCUSSION

The results revealed significant effects of various ash treatments on the morphological traits of both Kurrajong and Scots pine seedlings. Noteworthy differences were observed between the ash-treated groups and the control groups concerning growth parameters, such as seedling length, diameter, and the fresh and dry weight of the seedlings. Ash application appeared to stimulate seedling growth and positively influence their morphological development. However, toxic effects or heavy metal accumulation of the treatments were not discussed or considered in the study. Couch *et al.* (2021) reported that the application of wood ash did not adversely affect the growth of *Picea mariana* and *P. glauca* seedlings, with the best results observed at an application rate of 10,000 kg/ha. Similarly, Jansone *et al.* (2020) found that wood ash application improved soil macro- and micronutrient content, positively impacting the growth of *Picea abies* and *Pinus sylvestris* seedlings. Deighton and Watmough (2020) observed increased leaf nutrient concentrations in *Acer saccharum* seedlings following the application of nonindustrial wood ash. Singh *et al.* (1997) noted that low FA densities enhanced seed germination and seedling growth, while higher concentrations delayed or inhibited these processes. Additionally, Rajashekhar *et al.* (2017) reported increased plant growth and germination rates with FA mixed with organic substrates, while Shukla and Mishra (1986) observed increased biomass production and plant growth with FA mixed with soil at an optimum 20% level, although higher concentrations led to decreased bio-concentration of micronutrients.

In a study by De Quadros *et al.* (2021), wood ash application did not affect tree growth in *Pinus taeda*. Mandre *et al.* (2004) found that wood ash application inhibited height growth of *Picea abies* seedlings but stimulated root biomass (Mandre *et al.*, 2004). Previous examinations of ash's short-term effects on the growth and nutrition of tree seedlings native to eastern North America showed relatively neutral effects at doses up to 10 mg/ha and adverse effects at dosages of 15–20 mg/ha (Gorgolewski, 2015). The literature suggests that ash's effect on seedling growth is concentration-dependent, with low concentrations potentially enhancing growth and high concentrations potentially causing negative impacts.

Moreover, when considering seedling types based on species, container seedlings for Kurrajong and bare-root seedlings for Scots pine exhibited superior development. Similar studies on *Pinus brutia* (Ozel *et al.*, 2018), *Cupressus sempervirens* and *Cupressus arizonica* also demonstrated better development with container seedlings (Ayan *et al.*, 2020). Quality parameters such as DQI and SQ were also assessed. The ash-treated groups exhibited higher DQI values, indicating healthier seedlings with superior growth. Similarly, SQ values were higher in the ash-treated groups compared to the control groups. Other studies investigating ash applications on soil condition, nutrition, and growth in *Pinus radiata* plantations reported positive effects on seedling quality (Omil *et al.*, 2011; Arshad *et al.*, 2020). In summary, the effect of ash use on seedling quality is complex and depends on ash type, plant species, and application rate.

***Conclusion*:** The findings of this study indicate that the utilization of ash, a waste material, enhanced the morphology and quality of Kurrajong and Scots pine seedlings. When employing ash, several factors need to be considered, including the source of the ash, ash density, ash particle size, the amount of ash applied, and the selection of seedling species for cultivation. The integration of ash in forestry applications signifies a substantial stride toward waste management and the advancement of sustainability. However, additional research is required, and various factors and characters including physiological and soot-root ratio need to be considered for accurate conclusion in the field and nursery performances of the species and treatments. The outcomes of this study underscore the potential advantages of ash utilization in the forestry industry and provide guidance for future research.

***Conflicts of Interest*:** The author declares no conflict of interest.

***Author Contributions*:** Durmus Cetinkaya conceived the idea and finalized the manuscript.

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REFERENCES

Antonkiewicz, J., A. Popławska, B. Kołodziej, K. Ciarkowska, F. Gambuś, M. Bryk and J. Babula. 2020. Application of ash and municipal sewage sludge as macronutrient sources in sustainable plant biomass production. Journal of Environmental Management 264:110450.

Arshad, S., M.Z. Iqbal, M. Shafiq, M.A. Tariq, M.A. Kabir and Z.U.R. Farooqi. 2020. Azadirachta Indica A. Juss: Wood Ash Affects Seedling Growth of Mung Bean Vigna Radiata L.. European Journal of Agriculture and Food Sciences 2:1.

Assi, A., F. Bilo, A. Zanoletti, J. Ponti, A. Valsesia, R. La Spina, L.E. Depero and E. Bontempi. 2020. Review of the reuse possibilities concerning ash residues from thermal process in a medium-sized urban system in Northern Italy. Sustainability 12:4193.

Ayan, S., E. Civek, E.N.Y. Çelik, O. Gülseven, Ş.S. Akin and E. Yilmaz. 2020. Morphological quality characteristics of Mediterranean and Arizona cypresses seedlings. Journal of Bartin Faculty of Forestry 22:580-590.

Bolou, G.A., K.A. Kouamé, C.O.P. Ogui and D.A.D. Nassa. 2021. Urban biodiversity in the light of the dynamics of industrial activities in San-Pedro (south-west of the ivory coast). The International Journal of Social Sciences and Humanities Invention 8:6475-6487.

Couch, R.L., N. Luckai, D. Morris and A. Diochon. 2021. Short-term effects of wood ash application on soil properties, growth, and foliar nutrition of *Picea mariana* and *Picea glauca* seedlings in a plantation trial. Canadian Journal of Soil Science 101:203-215.

de Quadros, L.P., H.A.S. Ducheiko, S. Maeda, S.A. Prior, E.M. Araújo, J.B.V. Gomes, I.A. Bognola, M.T.S. Soares, E. Magri, C. Frigo, A. Kawasaki and A.C.V. Motta. 2021. Effects of wood ash application on tree nutrition and soil dynamics in a *Pinus taeda* system. Forest Science 67:618-628.

Deighton, H.D. and S.A. Watmough. 2020. Effects of non-industrial wood ash (NIWA) applications on soil chemistry and sugar maple (*Acer saccharum* Marsh.) seedling growth in an acidic Sugar Bush in central Ontario Forests 11:693

Dickson, A., A.L. Leaf and J.F. Hosner. 1960. Quality appraisal of white spruce and White Pine seedling stock in nurseries. The Forestry Chronicle 36:10-13.

Gorgolewski, A. 2015. Wood ash as a forest soil amendment: Effects on seedling growth and nutrition, and red-backed salamander abundance. Master thesis, University of Toronto 1604366.

Halkos, G. and K.N. Petrou. 2016. Efficient waste management practices: A review. Munich Personal RePEc Archive.71518

He, H., Z. Dong, Q. Peng, X. Wang, C. Fan and X. Zhang. 2017. Impacts of coal fly ash on plant growth and accumulation of essential nutrients and trace elements by alfalfa (*Medicago sativa*) grown in a loessial soil. Journal of Environmental Management 197:428-439.

Jansone, B., V. Samariks, M. Okmanis, D. Kļaviņa and D. Lazdiņa. 2020. Effect of high concentrations of wood ash on soil properties and development of young Norway spruce (Picea abies (L.) Karst) and Scots pine (*Pinus sylvestris* L.). Sustainability 12:9479.

Johan, P.D., O.H. Ahmed, L. Omar and N.A. Hasbullah. 2021. Phosphorus transformation in soils following co-application of charcoal and wood ash. Agronomy 11:2010.

Lazdiņa, D., I. Bebre, K. Dumiņš, I. Skranda, A. Lazdiņš, J. Jansons and S. Celma. 2017. Wood ash-green energy production side product as fertilizer for vigorous forest plantations. Agronomy research 15:468-477.

Mandre, M., R. Korsjukov and K. Ots. 2004. Effect of wood ash application on the biomass distribution and physiological state of Norway spruce seedlings on sandy soils. Plant and Soil 265:301-314.

Ohno, T. and M.S. Erich. 1990. Effect of wood ash application on soil pH and soil test nutrient levels. Agriculture, Ecosystems & Environment 32:223-239.

Omil, B., F. Sánchez-Rodríguez and A. Merino. 2011. Effects of ash applications on soil status, nutrition, and growth of *Pinus radiata* D. don plantations. Recycling of Biomass Ashes. Springer Berlin Heidelberg, Berlin, Heidelberg. pp.69-86.

Ots, K., M. Tilk and K. Aguraijuja. 2017. The effect of oil shale ash and mixtures of wood ash and oil shale ash on the above- and belowground biomass formation of Silver birch and Scots pine seedlings on a cutaway peatland. Ecological Engineering 108:296-306.

Ozel, H.B., C. Yücedağ, N. Bilir, Z. Olmez and V. Aydinhan. 2018. The effect of seedling types on morphological characteristics in turkish red pine (*Pinus brutia* Ten.) seedlings. Bartın University International Journal of Natural and Applied Sciences 1:43-47.

Pärn, H., M. Mandre, K. Ots, J. Klõšeiko, A. Lukjanova and T. Kuznetsova. 2010. Use of biofuel ashes in forestry. Forestry Studies 52:40-59.

Quirantes, M., F. Calvo, E. Romero and R. Nogales. 2016. Soil-nutrient availability affected by different biomass-ash applications. Journal of soil science and plant nutrition 16:159–163.

Rajashekhar, L., C.K. Manjunatha and G.P. Geetha. 2017. Effect of fly ash added pot mixture on growth and development of nursery seedlings of *Simarouba glauca*. Journal of Pharmacognosy and Phytochemistry 6:1616-1621.

Rajeshkumar, V., K.S. Elango, D. Vivek, S. Anandaraj, C. Vinodhini and P. Kamalakannan. 2021. Experimental investigation of organic waste ash in concrete. IOP Conference Series: Materials Science and Engineering 1145:012018.

Raven, P.H. and D.L. Wagner. 2021. Agricultural intensification and climate change are rapidly decreasing insect biodiversity. Proceedings of the National Academy of Sciences of the United States of America 118: e2002548117.

Romanowska-Duda, Z., K. Piotrowski, B. Wolska, M. Debowski, M. Zielinski, P. Dziugan and S. Szufa. 2020. Stimulating effect of ash from sorghum on the growth of lemnaceae-A new source of energy biomass. Springer Proceedings in Energy. Springer International Publishing, Cham. pp.341-349.

Scheepers, G.P. and B. du Toit. 2016. Potential use of wood ash in South African forestry: a review. Southern Forests: a Journal of Forest Science 78:255-266.

Shi, R., J. Li, J. Jiang, K. Mehmood, Y. Liu, R. Xu and W. Qian. 2017. Characteristics of biomass ashes from different materials and their ameliorative effects on acid soils. Journal of Environmental Sciences 55:294-302.

Shukla, K.N. and L.C. Mishra. 1986. Effect of fly ash extract on growth and development of corn and soybean seedlings. Water, Air, and Soil Pollution 27:155-67.

Singh, S.N., K. Kulshreshtha and K.J. Ahmad. 1997. Impact of fly ash soil amendment on seed germination, seedling growth and metal composition of *Vicia faba* L. Ecological Engineering 9:203-208.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry The Principles and Practice of Statistics in Biological Research. 3rd edition, W.h. Freeman and Company, New York *247*, 326.

Thomas, B.S., J. Yang, K.H. Mo, J.A. Abdalla, R.A. Hawileh and E. Ariyachandra. 2021. Biomass ashes from agricultural wastes as supplementary cementitious materials or aggregate replacement in cement/geopolymer concrete: A comprehensive review. Journal of Building Engineering 40:102332.