

Research

Allelopathic effects of leaf powder from selected agroforestry tree species on the germination, growth, and yield of staple crops in a semiarid region

Berihu Abraha¹ · Emiru Birhane^{2,3,4} · Tesfay Gidey^{5,6} · Abadi Tesfay^{2,7} · Zenebe Girmay Siyum^{3,8} · Gebreyohannes Grimay²

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Abstract

Agroforestry (AF) systems improve ecological interactions and reduce environmental stresses in semiarid regions, thereby improving food security and livelihood. While many AF trees benefit crop growth, some may have inhibitory effects. Hence, assessing tree-crop interactions is essential to optimizing AF practices in semiarid regions. This study examines the allelopathic effects of *Dodonaea angustifolia* and *Populus deltoides* leaf powder on wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) germination, growth, and yield. A pot experiment was conducted in Ganta Afeshum district, northern Ethiopia, using four concentrations of leaf powder (50, 100, 150, and 200 g per pot) mixed with soil, alongside a control (without leaf powder). Wheat germination and yield decreased by 10% and 15%, and 16 and 13%, respectively, as the concentrations of *D. angustifolia* and *P. deltoides* leaf powder increased to 200 g. Similarly, the addition of 200 g of *D. angustifolia* and *P. deltoides* leaf powder reduced barley germination by 13% and 14%, and its yield by 18% and 15%, respectively. These findings suggest that integrating *D. angustifolia* and *P. deltoides* into AF systems may reduce wheat and barley productivity in semiarid regions. Further long-term field studies are needed to confirm and expand upon these findings.

Article Highlights

- *D. angustifolia* and *P. deltoides* leaf-based allelopathy reduced wheat and barley germination and early growth
- Leaf-based allelopathic chemicals from *D. angustifolia* and *P. deltoides* reduced wheat and barley yields
- Integrating *D. angustifolia* and *P. deltoides* into wheat or barley fields may reduce productivity in semiarid regions

Keywords Allelopathy · Leaf powder · *Dodonaea angustifolia* · Crop yield · Germination inhibition · *Populus deltoides* · Semiarid agroforestry

✉ Tesfay Gidey, tglove.gidey@gmail.com | ¹Agriculture and Rural Development Office, Ganta Afeshum District, Adigrat, Ethiopia. ²Department of Land Resource Management and Environmental Protection, College of Dryland Agriculture and Natural Resources, Mekelle University, P.O. Box 231, Mekelle, Ethiopia. ³Institute of Climate and Society, Mekelle University, P.O. Box 231, Mekelle, Ethiopia. ⁴Faculty of Bioscience and Aquaculture, Nord University, P.O. Box 2501, NO-7729 Steinkjer, Norway. ⁵Department of Plant Science, College of Agriculture and Environmental Sciences, Adigrat University, P.O. Box 50, Adigrat, Ethiopia. ⁶Department of Forest Botany, Dendrology and Geobiocoenology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská, 1613 00 Brno, Czech Republic. ⁷Department of Earth and Environmental Sciences, Faculty of Bioscience Engineering, KU Leuven-University, Celestijnenlaan 200e–bus 2411, 3001 Leuven, Belgium. ⁸Centre for Environmental Policy, Imperial College London, London SW7 1 NE, United Kingdom.



1 Introduction

Agroforestry (AF) is the practice of integrating tree species into crop or pasture-based farming systems to improve agricultural productivity while providing numerous ecological benefits. It improves soil health and biodiversity, reduces biotic and abiotic stresses [1, 2], and increases the availability of food, fodder, firewood and timber, particularly in semiarid areas [3]. As a result, AF enhances the livelihoods and food security of smallholder farmers [1, 2, 4]. Additionally, it strengthens smallholder farmers' resilience and adaptation to climatic shocks, including recurrent drought and food shortages [2, 5, 6]. Despite its benefits, AF can also have negative effects on associated crops [7, 8, 46]. For example, the shade cast by trees can reduce the amount of light available underneath crops, thus limiting photosynthetic activity and ultimately decreasing crop yields [9, 42, 46]. Additionally, trees release allelopathic chemicals, such as phytotoxic substances, into the soil through processes like leaching and the decomposition of leaf litter [10, 11]. While all plant parts of trees in AF can produce allelopathic compounds, the leaves are particularly significant. This is because they tend to decompose rapidly, releasing the highest concentrations of allelopathic chemicals, which can inhibit the growth of associated crops [12, 13, 44, 46]. While these chemicals may occasionally promote ecological complementarity in AF systems by stimulating soil microbial activity [14, 15], they more commonly exert inhibitory effects. These effects manifest both directly, by interfering with photosynthesis and metabolic processes in crops, and indirectly, by altering soil properties that affect crop growth and development [12, 13, 16, 17, 44–46, 48].

Parklands are prominent type of AF practices in semiarid regions of Ethiopia, characterized by scattered trees and shrubs integrated into cultivated croplands [18]. Both *Dodonaea angustifolia* L.f. and *Populus deltoides* Bartr. ex Marsh. are among the most integrated tree species with crops in the parklands [17, 19]. *D. angustifolia* is a small evergreen tree or shrub, typically reaching up to 8 m in height. It mainly grows at altitudes between 800 and 2650 m in regions with annual rainfall ranging between 500 and 1500 mm [20]. *P. deltoides* is a deciduous, short-lived tree that can grow up to 30 m tall. It thrives in various climates, including semiarid regions, with annual rainfall ranging from 600 to 2000 mm [19]. Agroforestry systems that integrating *D. angustifolia* and *P. deltoides* have been shown to enhance crop productivity and income [21–23], while also providing several ecosystem services such as soil fertility improvement and carbon sequestration [20, 23]. Additionally, both species are valued for their medicinal uses, firewood, poles, fences, soil and water conservation, and their role in climate change adaptation [19, 20].

Despite the well-documented economic and ecological benefits of *D. angustifolia* and *P. deltoides*-based AF practices in semiarid regions [19, 21–23], recent studies have highlighted potential negative impacts on associated crops due to allelopathic effects [10, 17, 19, 24, 47, 48]. For example, allelopathic chemicals found in the leaves of the trees may inhibit the photosynthesis and metabolic processes of associated crops, thereby reducing their growth and yield [13, 17, 33, 34, 47, 48]. These chemicals can also alter soil physical, chemical, and biological properties, which may impair the growth and development of associated crops [17, 25, 34, 48]. Besides, phytotoxic chemicals released from *P. deltoides* through leaching and litter decomposition can reduce the growth of associated crops such as rice [25, 47]. However, studies on the effects of these trees on other crops, particularly wheat and barley, remain limited. Furthermore, the interaction between tree leaf-derived allelopathic compounds and crop performance under varying environmental conditions has not been thoroughly explored. Given the importance of identifying tree species that are compatible with crops in AF systems, understanding the full scope of allelopathic effects is essential for optimizing these systems for both productivity and sustainability [48]. Thus, a comprehensive study on the allelopathic impacts of *D. angustifolia* and *P. deltoides* on staple crops like wheat and barley is needed to bridge this knowledge gap. This study aims to investigate the inhibitory effects of *D. angustifolia* and *P. deltoides* leaf powder on seed germination, growth, yield and yield components of wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) in the semiarid region of northern Ethiopia. We hypothesized that crop germination, growth, and yield will decrease as the concentration of tree leaf powder in the soil increases.

The findings of the study have significant implications for the design and management of AF systems in semiarid regions. By identifying the potential allelopathic effects of *D. angustifolia* and *P. deltoides* on staple crops, the study will inform the selection of tree species that can be integrated into AF systems without compromising crop productivity. Moreover, understanding the interaction between tree-derived chemicals and crop growth could lead to better management practices that enhance the sustainability of AF systems and improve food security in resource-limited areas.

2 Methods

2.1 Study area

Pot experiment for the study was carried out in 2020 at a nursery site, located in Adigrat town, Ganta Afeshum district, northern Ethiopia (Fig. 1). The area is found 120 km north of Mekelle city, the capital of Tigray, and is 921 km away from Addis Ababa, the capital city of Ethiopia. The study district is geographically located at 14°08'00"–14°17'20" N and 39°16'00"–39°33'20" E (Fig. 1) with an altitude range of 1400–3200 m. The area is characterized by semiarid climatic conditions, with annual rainfall of 450–850 mm, and the monthly temperature varies between 10–32 °C [4]. The area includes various land-use types such as cropland, pastureland, home garden, woodland, evergreen scrub and bare land. *Rhamnus prinoides* [4], *D. angustifolia* and *P. deltooides* are among the common AF tree species integrated with staple crops such as wheat and barley in the area. Agriculture, particularly the mixed crop-livestock farming system, is the primary economic activity of the study area [4].

2.2 Soil sampling and laboratory analyses

To obtain baseline soil fertility data before the experiment, soil samples (0–30 cm depth) were collected from 20 randomly selected spots near the nursery area, where *D. angustifolia* and *P. deltooides*-based AF systems are commonly practiced. The collected samples were thoroughly mixed, and a 300 g composite soil sample was taken for analysis. The samples were air-dried and sieved before undergoing physical and chemical analyses in the soil laboratory at Mekelle University, Ethiopia. Soil texture was determined using the hydrometer method [28]. Soil pH and electrical conductivity (EC) were determined by the suspension of the 1:2.5 ratio of soil to water. Soil pH was measured with a digital pH meter while EC was determined by conductivity meter following the methods of [29]. Soil organic carbon (OC) was analyzed using the Walkley and Black methods [30]. Total nitrogen (TN) and available soil Phosphorus (Av. P) were determined using the Micro-Kjeldahl and Olsen methods [31, 32], respectively. The Error! Reference source not found. soil physical and chemical properties of the study area are presented in Error! Reference source not found.

2.3 Leaf collection and powder preparation

Forty healthy, fully matured and fresh green leaves of *D. angustifolia* and *P. deltooides* were randomly collected from AF-based systems of these species, located near to the nursery, in August 2020, when the trees had reached the flowering stage. The leaves from each tree were thoroughly mixed, then washed, air-dried, and sun-dried for about two weeks

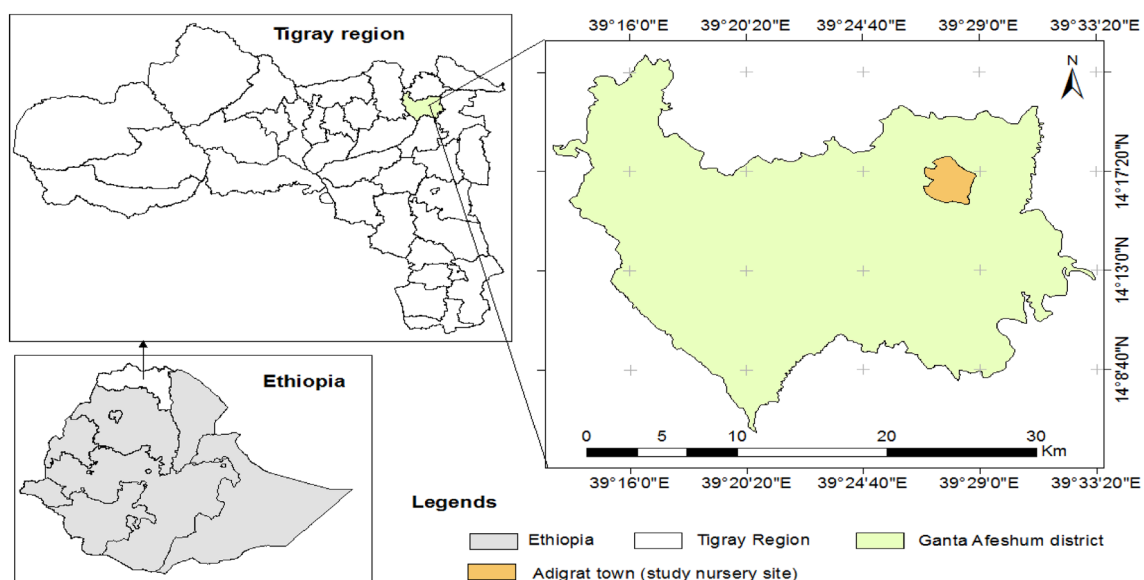
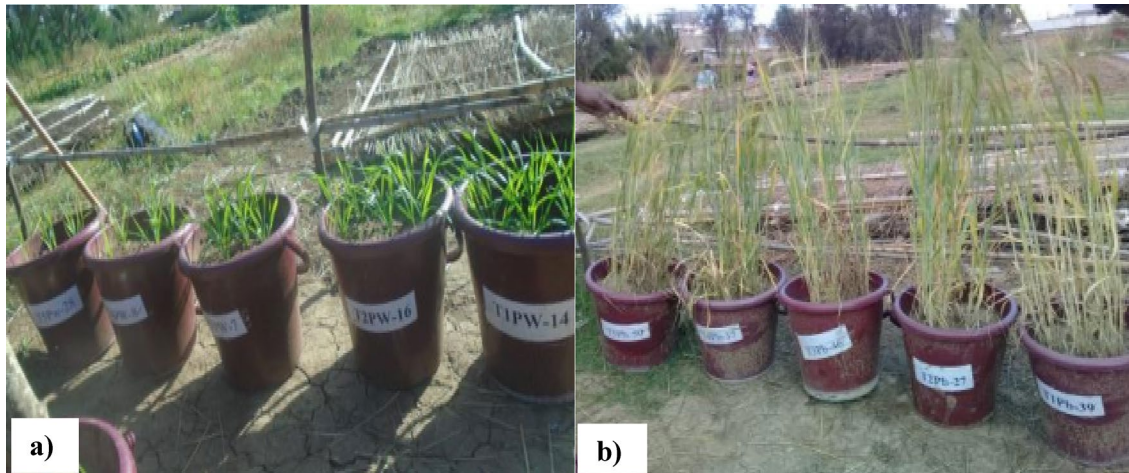


Fig. 1 Location of the study area

Table 1 Soil physical and chemical properties of the study area

Parameter	Value	Parameter	Value
Sand (%)	49	EC (dSm ⁻¹)	0.1
Silt (%)	30	OC (%)	1.56
Clay (%)	21	TN (%)	0.147
Texture	Sandy loam	Av. P (mg kg ⁻¹)	3.61
Soil pH (1:2.5 H ₂ O)	7.9		

**Fig. 2** The study crops at different growth stages: **a)** early growth of wheat, and **b)** barley at physiological maturity, in Adigrat town nursery site, Ganta Afeshum district, northern Ethiopia

under shaded conditions, following the procedure of Satapathy et al. [27]. The leaves were crushed into a fine powder by using a mechanical grinder, passed through a 2 mm mesh sieve, and the powder of each tree were kept in plastic bags for the experiment. The allelopathic compounds present in the leaf of *D. angustifolia* and *P. deltoides* primarily consist of phenols and flavonoids. Previous studies have reported that the phenolic and flavonoid content in *D. angustifolia* leaf ranges from 0.02 to 0.04 mg per gram dry weight [33, 34]. In contrast, the phenolic content in *P. deltoides* leaf is considerably higher, ranging between 0.59 and 0.67 mg per gram of dry weight [17]. These compounds are thought to play a significant role in the allelopathic effects of these tree species on associated crops.

2.4 Experimental design and management

Pure seeds of the commonly grown wheat (Picaflor variety) and barley (landrace) in the area were obtained from Ganta Afeshum district, northern Ethiopia for the experiment. The Picaflor wheat variety is known for its early maturity, requiring approximately 95–105 days from sowing to reach physiological maturity. This variety typically grows to a height of 90–100 cm, making it well-suited for the study area's climate and growing conditions. The barley landrace variety, also characterized by early maturity, takes around 100–110 days from sowing to maturity. It generally reaches a height of 85–95 cm. Each crop (wheat and barley) was sown with ten seeds in pre-prepared pots, each covering a surface area of 0.25 m². The pots were filled with 21 kg of soil collected from areas adjacent to the nursery. The physical and chemical properties of the soil are provided in Table 1. To assess the allelopathic effects of tree leaf powder, the subsurface soil (3–5 cm) of each pot was thoroughly mixed with leaf powder from either *D. angustifolia* or *P. deltoides*, applied at four concentration levels: 50, 100, 150, and 200 g per pot, following the procedure of Iqbal et al. [48]. A control treatment was included, where no leaf powder was added to the soil. The experiment followed a completely randomized design with three replications. Crop seeds were sown on September 2, 2020. To maintain optimal moisture levels, 0.8 L of water was added to each pot every two days. Hand weeding and hoeing were performed manually at four and eight weeks after sowing to ensure proper crop growth and minimize weed competition. At the end of the growing period, the crops were manually harvested on December 15, 2020. The experimental pots at different growth stages of the crops are depicted in Fig. 2.

2.5 Data collection

The germination percentage in each pot was determined ten days after sowing using the formula developed by Bewley and Black [35]. After 30 days of sowing, three seedlings were randomly uprooted from each pot to measure seedling sizes (shoot and root lengths), and seedling dry biomass. Shoot and root lengths were measured using a tape meter. The uprooted seedlings were thoroughly washed and air-dried. The shoot and root dry weights of each seedling were separated and then weighed using a digital balance after being oven-dried for 24 h at a temperature of 73 °C [27, 47, 48]. Besides, at physiological maturity, the remaining plants in each pot were harvested to measure spike length, and counted the number of tillers per plant. The plants were then oven-dried for 72 h at 60 °C, and manually threshed, and their seeds were adjusted to a constant moisture level of 12% to determine grain yields.

$$\text{Germination (\%)} = \frac{\text{Number of germinated seeds}}{\text{Total number of sown sees}} \times 100 \quad (1)$$

2.6 Statistical analyses

Data were analyzed using analysis of variance (ANOVA) with general linear models [36]. Prior to analyses, the normality of the data was tested using the Shapiro-Wilk test at the 5% significance level. In the model, the leaf powder concentrations of each tree species were treated as fixed factors, while replication was considered a random effect. The F-test from the ANOVA was used to determine if significant differences existed between the treatments. When the F-test indicated significant differences, Fischer's Least Significant Difference (LSD) test at the 5% probability level was employed to compare the means of the treatments, and identify which specific concentrations differed from each other. This approach ensured robust analyses of the effects of varying leaf powder concentrations on germination, growth and yield of the crops.

3 Results

3.1 Effects of leaf powder on wheat germination, growth and yield

The leaf powder concentrations from both AF tree species significantly ($p < 0.05$) affected germination, growth and yield of wheat. Specifically, adding of 200 g of leaf powder to soil reduced the wheat germination rates by 10 and 15% when the powder source was *D. angustifolia* and *P. deltoides*, respectively, compared to the control. At this concentration, the application of *D. angustifolia* leaf powder led to a 33% decrease in shoot length and a 26% reduction in shoot dry weight relative to the control (Table 2). Similarly, the addition of 200 g of *P. deltoides* leaf powder caused a 20% decrease in shoot length and a 19% reduction in shoot dry weight compared to the control (Table 2). Furthermore, wheat plants grown in soil mixed with 200 g of *D. angustifolia* and *P. deltoides* leaf powder exhibited a 24 and 23% decrease, respectively, in the

Table 2 Effects of leaf powder of *D. angustifolia* and *P. deltoides* on wheat germination and early growth parameters

Parameters	Leaf powder sources	Treatments (g of leaf powder pot ⁻¹)					p-value
		0	50	100	150	200	
Germination (%)	<i>D. angustifolia</i>	83.3 ^a	81.2 ^{ab}	78.3 ^b	77.2 ^b	75.8 ^b	0.023
	<i>P. deltoides</i>	91.7 ^a	88.2 ^{ab}	87.0 ^{ab}	85.5 ^b	79.5 ^c	0.034
Shoot length (cm)	<i>D. angustifolia</i>	28.1 ^a	25.9 ^b	23.3 ^c	21.3 ^d	21.0 ^d	0.014
	<i>P. deltoides</i>	30.6 ^a	29.1 ^{ab}	27.2 ^{abc}	26.9 ^{bc}	25.6 ^c	0.028
Root length (cm)	<i>D. angustifolia</i>	29.8	28.3	27.2	27.0	27.1	0.552
	<i>P. deltoides</i>	30.4	29.2	28.3	28.9	28.6	0.946
Shoot dry weight (g)	<i>D. angustifolia</i>	1.00 ^a	0.98 ^{ab}	0.89 ^b	0.81 ^{bc}	0.79 ^c	0.029
	<i>P. deltoides</i>	1.13 ^a	0.98 ^b	0.96 ^b	0.95 ^b	0.95 ^b	0.047
Root dry weight (g)	<i>D. angustifolia</i>	0.60	0.58	0.57	0.58	0.56	0.563
	<i>P. deltoides</i>	0.62	0.58	0.52	0.54	0.53	0.898

Means along row followed by the same letter(s) are not significantly different at $p < 0.05$

Table 3 Effects of leaf powder of *D. angustifolia* and *P. deltooides* on yield and yield components of wheat

Parameters	Leaf powder sources	Treatments (g of leaf powder pot ⁻¹)					p-value
		0	50	100	150	200	
Spike length (cm)	<i>D. angustifolia</i>	9.1 ^a	8.7 ^a	7.5 ^b	7.1 ^b	7.4 ^b	0.043
	<i>P. deltooides</i>	9.7 ^a	9.5 ^a	9.4 ^a	8.9 ^{ab}	7.8 ^b	0.044
Number of tillers plant ⁻¹	<i>D. angustifolia</i>	3.5 ^a	3.2 ^b	3.1 ^{bc}	2.9 ^d	2.8 ^d	0.037
	<i>P. deltooides</i>	3.7 ^a	3.6 ^{ab}	3.3 ^b	3.0 ^c	3.0 ^c	0.041
Grain yield (g pot ⁻¹)	<i>D. angustifolia</i>	30.0 ^a	28.5 ^b	26.1 ^c	26.4 ^{cd}	25.9 ^d	0.040
	<i>P. deltooides</i>	35.2 ^a	34.6 ^{ab}	33.8 ^{ab}	32.1 ^b	31.1 ^b	0.048

Means along row followed by the same letter(s) are not significantly different at $p < 0.05$

Table 4 Effects of leaf powder of *D. angustifolia* and *P. deltooides* on barley germination and early growth parameters

Parameters	Leaf powder sources	Treatments (g of leaf powder pot ⁻¹)					p-value
		0	50	100	150	200	
Germination (%)	<i>D. angustifolia</i>	93.8 ^a	91.6 ^{ab}	89.2 ^{abc}	85.5 ^{bc}	83.1 ^c	0.047
	<i>P. deltooides</i>	94.3 ^a	93.5 ^a	89.6 ^a	88.3 ^a	82.5 ^b	0.045
Shoot length (cm)	<i>D. angustifolia</i>	33.1 ^a	30.6 ^b	28.7 ^{bc}	26.1 ^c	25.6 ^c	0.023
	<i>P. deltooides</i>	34.2 ^a	33.3 ^{ab}	31.2 ^b	29.4 ^b	28.8 ^b	0.028
Root length (cm)	<i>D. angustifolia</i>	34.8	33.5	33.1	32.7	32.8	0.589
	<i>P. deltooides</i>	35.6	35.1	34.2	30.1	29.9	0.742
Shoot dry weight (g)	<i>D. angustifolia</i>	0.87 ^a	0.81 ^b	0.80 ^b	0.71 ^c	0.70 ^c	0.041
	<i>P. deltooides</i>	1.01 ^a	1.00 ^a	1.00 ^{ab}	0.93 ^b	0.90 ^b	0.046
Root dry weight (g)	<i>D. angustifolia</i>	0.67	0.64	0.62	0.60	0.58	0.637
	<i>P. deltooides</i>	0.68	0.56	0.50	0.51	0.48	0.424

Means along row followed by the same letter(s) are not significantly different at $p < 0.05$

number of tillers compared to the control. Notably, wheat grain yield was also significantly reduced, with a 16% decrease when *D. angustifolia* leaf powder was used, and a 13% reduction when *P. deltooides* leaf powder was applied (Table 3). However, no significant differences were observed among the treatments in terms of root length and root dry weight (Table 2). These results suggest that the allelopathic effects of leaf powder from both trees can inhibit various growth parameters and yield components of wheat.

3.2 Effects of leaf powder on barley germination, growth and yield

The leaf powder concentrations of *D. angustifolia* and *P. deltooides* significantly impacted ($p < 0.05$) on germination, growth and yield of barley. Compared to the control, 200 g of *D. angustifolia* and *P. deltooides* powder added to the soil, reduced barley germination by 13 and 14%, respectively. Mixing 200 g of *D. angustifolia* and *P. deltooides* leaf powder also decreased shoot length by 29 and 19%, respectively, compared to the control (Table 4). Barley grown in the soil mixed with 200 g of *D. angustifolia* and *P. deltooides* leaf powder had 24 and 12% lower shoot dry weight, respectively, compared to the control (Table 4). In addition, at the 200 g of *D. angustifolia* and *P. deltooides* leaf powder concentrations, the number of tillers was reduced by 20 and 23%, respectively, relative to the control. The grain yield of barley grown in soil with 200 g of *D. angustifolia* and *P. deltooides* leaf powder was 18 and 15% lower, respectively, compared to the control (Table 5). However, no significant differences were observed among the treatments for root length, spike length, and root dry weight (Tables 4 and 5).

4 Discussion

Our study highlighted that increasing the concentration of *D. angustifolia* and *P. deltooides* leaf-based allelopathic substances in the soil significantly reduced the germination, growth, and yield of wheat and barley. This effect could be attributed to allelopathic chemicals present in the leaves, such as phenols and flavonoids [17, 33, 34, 47, 48], which may

Table 5 Effects of leaf powder of *D. angustifolia* and *P. deltoides* on barley yield and yield components

Parameters	Leaf powder sources	Treatments (g of leaf powder pot ⁻¹)					p-value
		0	50	100	150	200	
Spike length (cm)	<i>D. angustifolia</i>	7.9	7.4	7.1	7.3	7.0	0.622
	<i>P. deltoides</i>	8.1	8.0	8.1	8.1	7.8	0.678
Number of tillers plant ⁻¹	<i>D. angustifolia</i>	3.6 ^a	3.5 ^a	3.5 ^a	3.1 ^b	3.0 ^b	0.001
	<i>P. deltoides</i>	4.2 ^a	4.0 ^{ab}	3.8 ^{abc}	3.6 ^{bc}	3.4 ^c	0.029
Grain yield (g pot ⁻¹)	<i>D. angustifolia</i>	24.0 ^a	24.0 ^a	21.1 ^c	20.4 ^d	20.3 ^d	0.041
	<i>P. deltoides</i>	26.2 ^a	26.1 ^a	24.3 ^b	23.9 ^b	22.7 ^b	0.045

Means along row followed by the same letter(s) are not significantly different at $p < 0.05$

inhibit the metabolic and enzymatic processes of crops, thereby reducing their growth, development, and ultimately, their yield and yield components [13, 17, 47, 48].

Furthermore, the phenolic compounds in *P. deltoides* leaves significantly inhibited the growth and yield of wheat and barley by disrupting their photosynthetic systems. These compounds reduced the concentrations of essential pigments, such as chlorophyll and carotenoids, which are crucial for efficient light absorption and photosynthesis. The decline in these pigments impaired the photosynthetic capacity of the crops, leading to reduced energy production and stunted growth [13, 43]. Additionally, phenolic compounds interfered with the synthesis of proteins and carbohydrates, processes vital for cell division, development, and overall crop vitality, thereby directly affecting crop yield.

Moreover, these allelopathic chemicals may alter soil properties, including physical, chemical, and biological factors, which play a critical role in regulating crop growth. Changes in soil pH, nutrient availability, microbial activity, and water retention can further impair the crops' ability to absorb essential minerals, exacerbating the negative effects on growth and yield [17, 25, 34, 48]. The combined impact of both direct physiological disruption and altered soil conditions highlights the complex interactions between *P. deltoides* leaf powder and the growth of wheat and barley crops. Similarly, allelopathic substances found in *Eucalyptus* leaves influenced the phosphorylation pathway and Magnesium activation in associated black gram crops. This, in turn, decreased the synthesis of carbohydrates, proteins, and nucleic acids, thereby reducing the crop's growth, early development, and yield [37, 45].

The findings of this study demonstrated that increasing the allelopathic concentrations of *D. angustifolia* and *P. deltoides* in the soil significantly decreased germination, growth and yield of wheat and barley. These results align with previous studies, which have similarly demonstrated the allelopathic effects of *P. deltoides* leaf powder on crop performance. For instance, increasing the concentration of *P. deltoides* leaf allelopathy in the soil from 0 to 25 g significantly reduced wheat germination rates, from 89% to 78%. This reduction in germination suggests that the allelopathic chemicals, such as phenolic compounds, released to the soil through leaf decomposition, adversely affect the early developmental stages of wheat, likely by interfering with seedling growth and metabolic processes necessary for successful germination. In addition to germination, the shoot biomass of wheat was also significantly impacted by higher leaf powder concentrations. As the concentration of *P. deltoides* leaf powder increased from 0 to 25 g, the shoot biomass of the crop decreased from 0.3 g to 0.16 g. This decline in shoot biomass indicates that the allelopathic compounds likely disrupt essential physiological functions, such as photosynthesis and nutrient uptake, which are critical for growth and biomass production. These results further emphasize the inhibitory effects of *P. deltoides* leaf allelopathy, suggesting that higher concentrations of leaf powder in the soil could lead to substantial reductions in crop growth and productivity. Like the current study, these observations highlight the significant impact of allelopathic chemicals on plant growth and yield, particularly in AF systems where tree-leaf decomposition plays a key role in altering soil dynamics [17, 47, 48].

In addition, increasing the leaf allelopathic chemicals of *P. deltoides* in the soil from 0 to 10%, decreased wheat germination rates from 40 to 10%, and the shoot length from 9.4 to 4.6 cm. In association with the latter parameter, the photosynthetic pigments like the carotenoids were found to decline from 61 to 23%, which significantly affected the photosynthesis and enzymatic activities of the crop [13]. Similarly, decreased sorghum shoot length and dry shoot weight, respectively from 8.5 to 5 cm, and 94 to 86 g when the *D. viscosa* (a species in the same genus as *D. angustifolia*) allelopathic concentrations in the soil rose from 0 to 10 g [38]. The allelopathic chemicals of *P. deltoides* also significantly affected germination, growth and yield of other crops such as maize, rice, sorghum and black gram [25, 39, 47]. Lower growth and yield performance of wheat, barley, maize and sorghum have been reported elsewhere in semiarid areas, where the crops are adjacently grown with the *Eucalyptus* species, which release allelopathic substances that inhibit crop growth and development [40, 41, 45].

The study demonstrated that the allelopathic chemicals from *D. angustifolia* and *P. deltooides* leaves had significant inhibitory effects on the germination, growth, and yield of wheat and barley, consistent with previous research conducted in semiarid regions [13, 17, 24, 38, 47]. These results support existing findings that allelopathic chemicals released by these tree species in AF systems can negatively impact crop performance, particularly in resource-limited environments. However, the findings contrast with studies emphasizing the economic and ecological benefits of *D. angustifolia* and *P. deltooides* in AF systems, particularly regarding soil quality improvement, biodiversity enhancement, and economic benefits for farmers [19, 21–23]. This discrepancy suggests that while these tree species may provide significant ecological advantages under certain conditions, their allelopathic effects can pose challenges to crop productivity, especially in semiarid regions. The conflicting outcomes highlight the need for a nuanced understanding of not only competition for essential growth resources, such as water, nutrients, and light, but also allelopathic interactions between trees and crops within AF systems. This underscores the importance of considering both ecological interactions and the specific compatibility of tree species with crops when advising farmers on AF practices. Future research should adopt a comprehensive approach that balances the ecological and economic benefits of tree species with their allelopathic effects to promote more sustainable and productive AF practices in semiarid regions [17, 26, 38].

5 Conclusions

The study demonstrated that increasing the concentration of *D. angustifolia* and *P. deltooides* leaf-based allelopathic chemicals from 0 to 200 g in the soil significantly reduced germination, growth, and yield of wheat and barley in the semiarid region of northern Ethiopia. These findings underscore the need for farmers and growers to exercise caution when selecting these tree species for integration with staple crops, such as wheat and barley, particularly in resource-limited environments. While the observed allelopathic effects are notable, it is important to recognize that tree-crop interactions in AF systems can vary depending on site-specific conditions, including soil properties and climatic factors. Given the potential for negative impacts on crop productivity, further investigation into the long-term effects of *D. angustifolia* and *P. deltooides* in AF systems is essential. Future research should prioritize long-term field studies to explore the cumulative effects of allelopathy over multiple growing seasons and to assess the ecological and economic sustainability of integrating these tree species with crops in semiarid areas. Additionally, future studies should examine the effects of different AF management practices, such as tree spacing and crop rotation, to mitigate allelopathic impacts while maximizing the benefits of tree integration. Comprehensive research is also needed to optimize tree-crop compatibility, enhance crop yields, and ensure the sustainability of AF systems in semiarid regions.

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Data availability Data sets used for this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

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Plant Guidelines The plants used in this study are collected from the Ganta Afeshum district, northern Ethiopia by Abraha. B, one of the authors of the manuscript. The collection of the plants used in the study complies with local and national guidelines and does not require further affirmation. Abraha. B and Birhane. E identified the plants materials, and voucher specimens with the IDs DA20201, PD20201, TE20201 and HV20201 were deposited at the Forestry Laboratory of Mekelle University, Ethiopia.

Permissions to collect plant parts All the plant parts collected with permissions.

Source of the plant seeds in the study All names used for the plants, and their seed sources were mentioned in the Methods section.

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References

1. Tadesse E, Abdulkedir A, Khamzina A, Son Y, et al. Contrasting species diversity and values in home gardens and traditional parkland agroforestry systems in Ethiopian Sub-Humid Lowlands. *Forests*. 2019;10:266. <https://doi.org/10.3390/f10030266>.
2. Wangai PW, Burkhard B, Müller F. A review of studies on ecosystem services in Africa. *J Sustain Built Environ*. 2016;5:225–45. <https://doi.org/10.1016/j.jbsbe.2016.08.005>.
3. Irisha J, Ilham J, Esa N. Contribution of local knowledge towards urban agroforestry as a sustainable approach on climate change adaptation. *EDP Sci*. 2018. <https://doi.org/10.1051/shsconf/20184503001>.
4. Gebremeske D, Birhane E, Rannestad MM, Gebre S, et al. Biomass and soil carbon stocks of *Rhamnus prinoides* based agroforestry practice with varied density in the drylands of Northern Ethiopia. *Agrofor Syst*. 2021;95:1275–93. <https://doi.org/10.1007/s10457-021-00608-8>.
5. Garrity DP, Akinnifesi FK, Ajayi OC, Weldesemayat SG, et al. Evergreen Agriculture: A robust approach to sustainable food security in Africa. *Food Secur*. 2010;2:197–214. <https://doi.org/10.1007/s12571-010-0070-7>.
6. Gidey T, Oliveira TS, Crous-Duran J, Palma JHN. Using the process-based Yield-Safe model to assess the impacts of climate change on yield of coffee under agroforestry and monoculture systems. *Agrofor Syst*. 2019;94:57–70. <https://doi.org/10.1007/s10457-019-00369-5>.
7. Iqbal J, Rauf HA, Shah AN, Shahzad B, et al. Allelopathic effects of Rose Wood, Guava, Eucalyptus, Sacred Fig and Jaman leaf litter on growth and yield of wheat (*Triticum Aestivum* L.) in a wheat-based agroforestry System. *Planta Daninha*. 2017;35:E017166992. <https://doi.org/10.1590/S0100-83582017350100060>.
8. Rizvi SJ, Tahir M, Rizvi V, Kohli RK, et al. Allelopathic interactions in agroforestry systems. *Crit Rev Plant Sci*. 1999;18:773–96. <https://doi.org/10.1080/07352689991309487>.
9. Garima KS, Meera D. Effect of allelochemicals present in *Populus deltoides* leaf extract on wheat (*Triticum aestivum*) in poplar based agroforestry system. *Int J Chem Stud*. 2017;5(3):785–7.
10. El-Rokiek Kowthar G, Rafat R, et al. The Allelopathic effect of mango leaves on the growth and propagative capacity of purple nutsedge (*Cyperus rotundus* L.). *Am J Sci*. 2010;6:151–9.
11. Tian G, Kang BT. Evaluation of phytotoxic effects of *Gliricidia sepium* (Jacq.) Walp. prunings on maize and cowpea seedlings. *Agrofor Syst*. 1994;26:249–54. <https://doi.org/10.1007/BF00711214>.
12. Jin H, Guo H, Yang X, Xin A, et al. Effect of allelochemicals, soil enzyme activity and environmental factors from *Stellera chamaejasme* L. on rhizosphere bacterial communities in the northern Tibetan Plateau. *Arch Agron Soil Sci*. 2022;68:547–60. <https://doi.org/10.1080/03650340.2020.1852549>.
13. Khaket T, Kumar V, Singh J, Dhanda S. Biochemical and physiological studies on the effects of senescence leaves of *Populus deltoides* on *Triticum vulgare*. *Sci World J*. 2014. <https://doi.org/10.1155/2014/126051>.
14. Cheng F, Cheng Z. Research progress on the use of plant allelopathy in agriculture and the physiological and ecological mechanism of allelopathy. *Front Plant Sci*. 2015. <https://doi.org/10.3389/fpls.2015.01020>.
15. Valiño A, Pardo-Muras M, Puig CG, López-Periágo JE. Biomass from Allelopathic agroforestry and invasive plant species as soil amendments for weed control—A Review. *Agronomy*. 2023;3:2880. <https://doi.org/10.3390/agronomy13122880>.
16. Rice EL. *Allelopathy*. 2nd ed. New York: Academic Press; 1984. p. 422.
17. Singh NB, Dinesh K, Rajesh G, Kadam S, Khan GH. Role of poplar in sustainable development of India. *Indian J Agrofor*. 2001;3:92–9.
18. Bishaw B, Abdelkadir A. Agroforestry and community forestry for rehabilitation of degraded watersheds on the Ethiopian highlands. *Combat Famine Ethiop*. 2003;7:1–22.
19. Suresh N, Verma A, Rana D, Bhardwaj R et al (2018) Poplar (*Populus deltoides*) based Agroforestry Systems: an economically viable livelihood option for the farmers of North India. *Climate change and agroforestry for mitigation, adaptation and livelihood security, a national report* pp. 18.
20. Bekele T (2000) Plant population dynamics of *Dodonaea angustifolia* and *Olea europaea* ssp. *cuspidata* in Dry Afromontane forests of Ethiopia. PhD thesis, Uppsala University, pp. 47.
21. Beshah F, Hunde Y, Getachew M, Bachhet RK, et al. Ethno pharmacological, phytochemistry and other potential applications of *Dodonaea* genus: A comprehensive review. *Curr Res Biotechnol*. 2020;2:103–19. <https://doi.org/10.1016/j.crbiot.2020.09.002>.

22. Chavan SB, Dhillon RS, Sirohi C, Keerthika A, et al. Enhancing farm income through boundary plantation of Poplar (*Populus deltoides*): An Economic Analysis. Sustainability. 2022;14:8663. <https://doi.org/10.3390/su14148663>.
23. Rizvi R, Handa AK, SridharSingh KB, et al. Contribution of *Populus deltoides* based agroforestry systems in atmospheric CO₂ reduction in northern states of Uttar Pradesh and Uttarakhand. Range Manag Agrofor. 2022;43:263–8.
24. Majeed A, Muhammad H, Ahmad H. Allelopathic effects of leaf extracts of three agroforestry trees on germination and early seedling growth of wheat (*Triticum aestivum* L.). Azarian J Agric. 2017;4:69–73.
25. Dhyani K, Singh N, Shukla A, Sahni S. Allelopathic effect of leaf extract of Poplar *deltoides* M. in seed germination, root characters and physiology of rice seedlings. Res Environ Life Sci. 2017;10:712–7.
26. Amoo SO, Ojo AU, Staden JV. Allelopathic potential of *Tetrapleura tetraptera* leaf extracts on early seedling growth of five agricultural crops. S Afr J Bot. 2008;74:149–52. <https://doi.org/10.1016/j.sajb.2007.08.010>.
27. Satapathy SR, Khanduri VP, Singh B, Riyal RM, et al. Allelopathic potential of *Ficus auriculata* and *Ficus semicordata* on growth of four traditional food crops of Garhwal Himalaya. Agric Food Res. 2022;9:100352. <https://doi.org/10.1016/j.jafr.2022.100352>.
28. Gee G, Bauder J (1982) Particle size analysis in methods of soil analysis. Agronomy no. 9, 2nd edn., Soil Science Society of America, Medison, USA.
29. Van Reeuwijk L (2002) Technical Paper 09: Procedures for Soil Analysis. Int Soil Ref Inf Cent Food Agric Organ United Nation.
30. Walkley A, Black I. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37:29–38.
31. Olsen SR (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture.
32. Ryan J, Estefan G, Rashid A (2001) Soil and plant analysis laboratory manual. 2nd edn. Jointly published by the International Center for Agricultural Research in the Dry Areas (ICARDA) and the National Agricultural Research Center (NARC). ICARDA, Aleppo, Syria.
33. Anode SH, Abraha T, Araya S. Oral and periodontal antibacterial activity of *Dodonaea angustifolia* plant extracts. J Pharmacognosy Phytother. 2018;7:1018–25.
34. Tessema FB, Gonfa YH, Asfaw TB, Tadesse MG, et al. Targeted HPTLC Profile, quantification of flavonoids and phenolic acids, and antimicrobial activity of *Dodonaea angustifolia* (L.f.) leaves and flowers. Molecules. 2023;28:2870. <https://doi.org/10.3390/molecules28062870>.
35. Bewley JD, Black M. Seeds: physiology of development and germination. Berlin: Springer Science & Business Media; 1994.
36. SAS (2003) SAS/STAT User's Guide, Version 9.2, SAS Institute, Cary, NC, USA.
37. Sasikumar K, Vijayalakshmi C, Parthiban KT. Allelopathic effects of *Eucalyptus* on blackgram (*Phaseolus mungo* L.). Allelopathy J. 2002;9:205–14.
38. Barkatullah F, Hussain M, Ibrar B. Allelopathic potential of *Dodonaea viscosa* (L.) Jacq. Pak J Bot. 2010;42:2383–90.
39. Hussain I, Jatoi SH, Nazir MJ, Haq U, et al. Allelopathic potential of Poplar (*Populus deltoides* L.) leaves aqueous extract on cereal crops. Pak J Agric Sci. 2022;35:1–11.
40. Alebachew M, Amare T, Wendie M. Investigation of the effects of *Eucalyptus camaldulensis* on performance of neighbouring crop productivity in Western Amhara, Ethiopia. Open Access J Sci. 2015;2:1–10. <https://doi.org/10.4236/oalib.1100992>.
41. Mohamadi N, Rajaie P. Effects of aqueous eucalyptus (*E. camaldulensis* Labill) extracts on seed germination, seedling growth and physiological responses of *Phaseolus vulgaris* and *Sorghum bicolor*. Res J Biol Sci. 2009;4:1292–6.
42. Sanna F, Campesi G, Deligios P, Ledda L, et al. Combined effects of microenvironment and land use on C fluxes in a Mediterranean agro-silvopastoral system. Eur J Agron. 2021;130:126348. <https://doi.org/10.1016/j.eja.2021.126348>.
43. Singh HP, Batish DR, Kohli RK. Effect of Poplar (*Populus deltoides*) shelterbelt on the growth and yield of wheat in Punjab, India. Agrofor Syst. 1998;40:207–13. <https://doi.org/10.1023/A:1005949818756>.
44. Ahmed TA, Elezz AA, Al-Sayed NH. Dataset of allelopathic effects of *Casuarina equisetifolia*-L leaf aquatic extract on seed germination and growth of selected plant crops. Data Brief. 2019;27:04770. <https://doi.org/10.1016/j.dib.2019.104770>.
45. Andualem AM, Aragaw MW, Molla AE, et al. Allelopathic effects of leaf extracts of *Eucalyptus camaldulensis* Dehnh. on morphological, physiological, and yield traits of Ethiopian wheat (*Triticum durum* L.) cultivars. BMC Plant Biol. 2024;24:1138. <https://doi.org/10.1186/s12870-024-05832-9>.
46. Abeje A, Anjulo A, Chauhan R. Allelopathic and shading effects of *Mangifera indica* L. on germination and early growth performance of associated crops. J Hortic For. 2023;15:12–9.
47. Abedi R, Abdi S. allelopathic potential of cottonwood (*Populus deltoides* bartr. ex marsh.) leaf extracts on some rice (*oryza sativa* L.) cultivars. Pol J Natur Sc. 2022;37:39–62.
48. Iqbal W, Siddiqui T, Ahmad I, Farooq M. Effect of allelochemicals present in leaf litter of *Bombax ceiba* L. and *Populus deltoides* L. tree species on wheat in agroforestry system. Appl Ecol Environ. 2022;20:4193–209.

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