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# Allelopathic effects of agroforestry tree, *Terminalia arjuna* Roxb. ex DC. on the germination, growth and physio-biochemical processes of *Triticum aestivum*

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## ABSTRACT

The present study was conducted to investigate the allelopathic effects of abscised plant parts of *Terminalia arjuna* on germination, growth, and physio-biochemical processes of *Triticum aestivum* L. Different doses of plant material obtained from fruits (F100 and F50), branches (B100 and B50), leaves (L100 and L50), and the mixture of all plant parts (A100) were applied to the seedbeds of two varieties of *T. aestivum*, DPW-62150 and DBW-17. It was observed that both the varieties differed in the intensity of response towards the treatments measured in terms of seed germination, shoot length, root length, dry weight, vigour index, tolerance index, total chlorophyll, nitrogen and organic carbon. The mixture of all the plant parts of *T. arjuna* stimulated most of the studied parameters and wheat variety DBW-17 performed better as compared to DPW-62150. A total of 49 allelochemicals were identified in the GC-MS analysis, of which 28, 28, and 30 were present in the fruit, branch and leaf powder, respectively. It can be inferred from the study that *T. aestivum*, particularly variety DBW-17, can be successfully intercropped with *T. arjuna*. However, further field studies should be undertaken on a wider scale to validate the results of this study.

**Key words:** Agroforestry, allelochemicals, allelopathy, arjuna tree, GC-MS, plant-plant interactions, *Terminalia arjuna*, *Triticum aestivum*, wheat crop

## INTRODUCTION

Agroforestry is a sustainable land use approach in which agricultural crops are sown with woody perennials to diversify and improve agronomic practices (10). It is a traditional system of land use with numerous socio-economic and environmental benefits (22). Agroforestry systems provide several ecosystem services, viz., carbon sequestration, biodiversity conservation, soil enrichment, reduction of soil erosion and maintenance of air and water quality (10). In addition, it can alleviate climate change effects, stabilize crops yields, increase productivity of lands, enhance tree cover outside the forest, improve land cover in crop fields and restore degraded ecosystems (19). Agroforestry practices provide economic benefits to farmers and environmental benefits to the society (22).

An assessment of positive and negative interactions between the woody perennials and crops can assist in selection of complementary crop species for agroforestry (15). Co-existing plant species often compete for niche space, and both above- and below-ground plant-plant interactions play a crucial role in determining their survival. These interactions are driven by secondary metabolites (also known as allelochemicals) and the phenomenon is known as allelopathy (17). In agroecosystems, several tree species, planted as shelterbelts, wind-breaks, boundaries and alleys, exert negative allelopathic influences on the crops, thus, adversely affecting their germination and growth (15,25). Therefore, it is important to

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identify the companion species with positive allelopathic interactions to develop sustainable agroforestry systems (25), Plate -1.


Plate 1. (A) Arjuna tree, (B) Senescent parts of tree i.e., fruit, branches and leaves, (C) Powder of senescent part of tree, (D) Pots containing powder of tree parts for allelopathic assessment, (E) Pots containing wheat seedlings.

Presence of various types of secondary metabolites in the plants make them highly beneficial for human being (35). *Terminalia arjuna* [(Roxb. ex DC.) Wight & Arn. (arjuna; Combretaceae)] is a tropical medicinal plant widely used in ayurveda for its curative properties viz., anticoagulant, hypocholesterolemic, antiviral, antibacterial, antifungal, hypolipidemic, antihypertensive and antithrombotic due to the presence of various types secondary metabolites (7). The tree is grown as an agroforestry species with wheat, rice and chickpea in Asia, Africa and America and also for land reclamation and timber production (25,31). *Triticum aestivum* L. (wheat; Poaceae) is a major winter food crop consumed in temperate and sub tropical regions of the world. The main use of the crop is for making flour, bread, biscuits, cookies, etc. Industrially, it is used in preparation of starch, gluten, malt, and distilled spirit. Wheat 'bran' is rich in protein and used as valuable livestock feed. India is the third largest producer of wheat and most of its population depends on it for dietery requirements (17).

Both *T. arjuna* and *T. aestivum* has often been recommended for agroforestry (13,16,23,25), but very little literature is available on their allelopathic effects as intercrops. Therefore, this study aimed to (a) investigate the positive or negative effects of abscised parts of *T. arjuna* on the germination, growth and physio-biochemical processes of

*T. aestivum* and (b) determine the secondary metabolites responsible for its allelopathic effects by Gas Chromatography and Mass Spectrometry (GC-MS) analysis.

## MATERIALS AND METHODS

Abscised parts of *T. arjuna* were collected from a tree growing in the campus of Chaudhary Charan Singh University, Meerut, Uttar Pradesh, India (28°44′-29°18′N and 77°08′-78°47′E; 228 m above sea level; 740 mm annual rainfall). A temporary fencing of 3 m radius was built around the tree trunk, with a total area of 28.28 $m^2$. After 7 days, the abscised parts accumulated in the understorey of tree were collected in the winter season, December 2020, when the tree was at leaf senescence stage. The fruits, branches/twigs and leaves were separately weighed, dried and powdered. Two varieties of wheat (*T. aestivum*), DPW-62150 and DBW-17, were procured from the local seed store and used as the test species. The study was done in earthen pots (16 cm height, 15 cm diameter and 1.76 $m^2$ area). The experimental treatments comprised of (i). 4-plant parts [fruits (F), branches (B), leaves (L), all plant parts (A)], (ii). 3-doses i.e., 0, 50 and 100 % of these powedered plants parts and (iii). two wheat varieties : DPW 62150 and DBW 17 as test species.

**Treatments**

Dry weight of collected fruits, branches, leaves and all plant parts were 330, 290, 480, and 1100 g, respectively. The dose of each treatment (g $pot^{-1}$) was calculated based on the dry weight of *T. arjuna* parts accumulated in 7 days under specified fenced area (28.28 $m^2$) around the tree trunk with respect to the pot area (1.76 $m^2$).

$$\text{Treatment} = \frac{\text{Dry weight of plant parts accumulated under tree fence} \times \text{Pot area}}{\text{Tree fence area}}$$

Using the above formula, the treatments of control (C), fruits [F100 (100 % conc.) and F50 (50 % conc.)], branches [B100 (100 % conc.) and B50 (50 % conc.)], leaves (L100 (100 % conc.) and L50 (50 % conc.)] and mixture of all plant parts (A100 [100 % conc.]) were prepared. The amount of biomass of fruits, branches, leaves, and all plant parts used for the preparation of different treatments is presented in Table 1.

Table 1. Quantity of plant material of *Terminalia arjuna* added per pot in different treatments

| Treatment dose (%) | Amount of plant material (g $pot^{-1}$) | | | |
|---|---|---|---|---|
| | Fruits (F) | Branches (B) | Leaves (L) | All plant parts (A) |
| Control (0) | 0.0 | 0.0 | 0.0 | 0.0 |
| 100 | 20.53 | 18.04 | 29.87 | 34.2 |
| 50 | 10.26 | 9.02 | 14.93 | - |

**Experimental design**

The experiment included 48 pots, each *T. aestivum* variety had 24 pots and 8 sets of treatments. The treatments were applied only once before sowing and replicated thrice in completely randomised design. Each pot contained 2 kg soil amended with different doses of plant material (C, F100, F50, B100, B50, L100, L50 and A100).

The seeds of the test plants (*T. aestivum* varieties DPW 62150 and DBW 17) were surface sterilized with sodium hypochlorite solution for 3-4 min. Thereafter, they were washed thoroughly under running tap water before sowing. In each pot, 20 seeds of

*T. aestivum* were sown at a depth of 1.5-2 cm in moist soil. The sowing was done on 20th Dec 2020 and the seedlings were harvested on 27th Dec 2020. The pots were regularly irrigated as and when required.

**Parameters studied**

**(i) Physical analysis**

**(a) Seed germination (%)** : Seed germination was recorded 5 days after sowing, in terms of radicle emergence. It was calculated as under:

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

**(b) Seedling root length (cm) and shoot length (cm)**: Seedling root and shoot length were determined 7 days after sowing using a line-gauge scale.

**(c) Seedling dry weight (mg)**: Seedling dry weight was recorded 7 days after sowing. For dry weight, the samples were dried in oven at 65 °C till a constant weight was achieved. Thereafter the weight was measured using a digital weighing balance (Kern & Sohn, Germany; ABS 220-4N; 0.1 mg).

**(d) Vigour Index and Tolerance Index (%)**: The Vigour Index and Tolerance Index in 7-day-old seedlings of *T. aestivum* were calculated by following formulae (1,30):

$$\text{Vigour Index} = (\text{Root length} + \text{Shoot length}) \times \text{percent germination}$$

$$\text{Tolerance Index (\%)} = \frac{\text{Length of longest root under treatment}}{\text{Length of longest root under control}} \times 100$$

**(ii) Biochemical analysis**

**(a) Total chlorophyll (mg $g^{-1}$ f. wt.):** Total chlorophyll content was estimated in 7-day-old seedlings of *T. aestivum*. Fifty milligrams of fresh leaves were homogenized in 10 ml of chilled 80 % acetone (20 ml distilled water and 80 ml acetone). The extract was centrifuged at 5000 rpm for 5 min in a cold centrifuge and the supernatant was collected. The final volume was made to 10 ml using 80 % acetone and absorbance was read at 645 nm and 663 nm on UV-1800 double beam spectrophotometer (Shimadzu, Japan) against 80 % acetone as blank. The chlorophyll content was calculated using the following formula (2):

$$\text{Total chlorophyll content (mg g}^{-1}\text{ f. wt.)} = \frac{20.2 \times (A_{645}) + 8.02 \times (A_{663}) \times V}{1000 \times W}$$

where, A : Absorbance of chlorophyll extract on specific wavelength, V : Final volume and W : Fresh weight of tissue (mg).

**(b) Nitrogen (mg $g^{-1}$ d.wt.):** Total nitrogen was estimated in 7-day-old seedlings as per Snell and Snell (28). Fifty milligrams of dried plant material were taken and digested with appropriate amounts of digestion mixture (5 ml of conc. $H_2SO_4$ and 2 ml of 30 % $H_2O_2$). The test tubes were kept in a sand bath for 30 min for digestion and then cooled at room temperature. Three milliliters of 30 % $H_2O_2$ were again added to each tube and the tubes were kept for further digestion till the digest became clear. Thereafter, the total volume was made 10 ml with distilled water. Finally 1 ml of digest, 3 ml of Nessler's reagent and 1 ml distilled water were

added. The absorbance of solution was recorded at 425 nm and the nitrogen content was determined using following formula:

$$\text{Nitrogen content (mg g}^{-1}\text{ d.wt.)} = \frac{1.4 \times \text{A} \times \text{V}}{\text{W}} \times \text{Dilution factor}$$

where, A : Absorbance at specific wavelength, V : Final volume and W : Fresh weight of tissue (mg)

**(c) Organic carbon (mg g$^{-1}$ d.wt.)**: Organic carbon was estimated in 7-day-old seedlings as per Datta *et al*. (4). One g of the dried plant material was taken in 100 ml conical flask and homogenized with 10 ml of 1N $K_2Cr_2O_2$, followed by addition of 20 ml of acidified silver sulfate (1.25g $Ag_2SO_4$ dissolved in 100 ml concentrated $H_2SO_4$). The flask was allowed to stand for 30 min and then the content was centrifuged at 5000 rpm. The supernatant was made to 30 ml with distilled water. A green chromium sulfate colour was developed and its absorbance was recorded at the wavelength of 660 nm using blank [(10 ml $K_2Cr_2O_7$ (without plant material) + 20 ml acidified silver sulfate)]. The carbon content was calculated using following formula:

$$\text{Organic carbon content (mg g}^{-1}\text{d.wt.)} = \frac{9.3 \times \text{A} \times \text{V}}{\text{W}} \times \text{Dilution factor}$$

where, A : Absorbance at specific wavelength, V : Final volume and W : Fresh weight of tissue (mg)

**Gas chromatography-mass spectrometry (GC-MS) analysis**

The GC-MS was performed in Central Instrumentation Lab., Central University of Punjab. Chloroform extracts of the dried and powdered plant material (fruits, branches and leaves) of *T. arjuna* were prepared by extracting 1 g powder with 250 ml chloroform in Soxhlet apparatus. When the extraction was complete, the solution was stored at 4 °C for GC-MS analysis. The analysis was done with a GCMS-QP2010 Ultra at 200 °C ion source temperature, 260 °C interface temperature and 4.50 min solvent cut time. The detector gain mode was relative (1.27 kV + 0.00 kV). Other working conditions were: column oven temperature- 70 °C, injection temperature- 250 °C, injection mode- split less, flow control mode pressure- 66.7 kPa, total flow- 14 ml min$^{-1}$, column flow- 1.07 ml min$^{-1}$ and linear flow- 3 ml min$^{-1}$. The compounds were identified matching their mass spectra with those in the National Institute of Standard and Technology mass spectra library (NIST11.lib) and Wiley library (WILEY8.LIB).

**Statistical analysis**

The results are presented as clustered histograms by calculating percent inhibition or stimulation in each parameter over control using MS Excel 2010.

## RESULTS AND DISCUSSION

The present study attempts to assess the suitability of *T. arjuna* as an agroforestry species by evaluating the allelopathic effect of its abscised parts (fruits, branches and leaves) on *T. aestivum* varieties DPW-62150 and DBW-17.

**Germination**

Compared to the control, wheat seed germination was inhibited by 11.43, 14.70, 2.63 and 5.40 % in DPW-62150 when subjected to F50, L100, L50 and A100, respectively, whereas it was stimulated by 2.5 % under B100 (Fig. 1). F100, L100, and L50 inhibited the seed germination in DBW-17 by 9.09 % each and on the contrary, F50, B100 and B50 stimulated it by 7.69 % each with respect to the control (Fig. 1). F100 and B50 had no effect on seed germination in DPW-62150 and A100 had no notable effect in DBW-17 (Fig. 1).

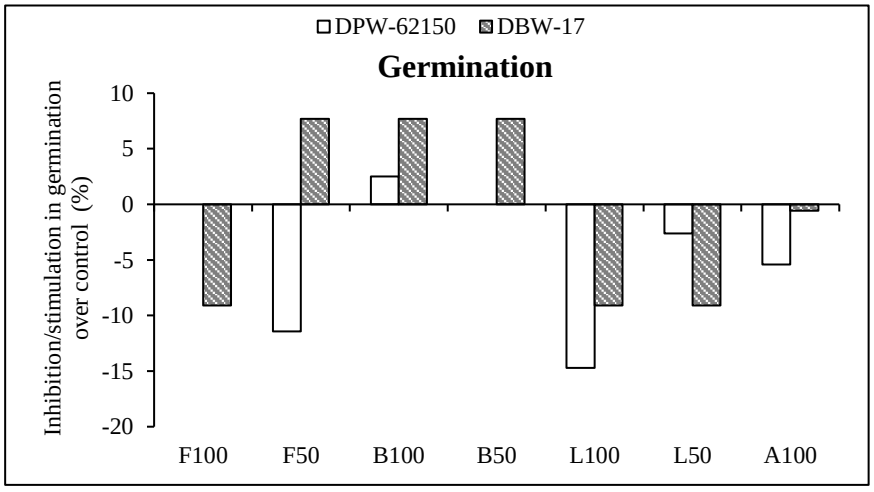


Figure 1. Effects of abscised plant parts of *Terminalia arjuna* on germination of *Triticum aestivum* variety DPW-62150 and DBW-17 five days after sowing. Data presented as inhibition/stimulation in different treatments over control. Treatments: F100: Fruit powder (20.53 g $pot^{-1}$); F50: Fruit powder (10.26 g $pot^{-1}$); B100: Branch powder (18.04g $pot^{-1}$); B50: Branch powder (9.02 g $pot^{-1}$); L100: Leaf powder (29.87g $pot^{-1}$); L50: Leaf powder (14.93 g $pot^{-1}$); and A100: Mixture of fruit, branch and leaf powder (34.26 g $pot^{-1}$)

**SEEDLING GROWTH**

**Soot Length:** Shoot length in the seedlings of wheat DPW-62150 was stimulated under all the treatments by 2.69-29.69 % compared to the control and the maximum increase was observed under the treatment of A100 (Fig. 2). Similarly, shoot length in DBW-17 was stimulated by all the treatments except F100, where it was mildly inhibited by 2.29 % over the control (Fig. 2). The maximum stimulation in the shoot length of DBW-17 was 22.72% with respect to control in treatment of A100 (Fig. 2). In contrast, root length in seedlings of DPW-62150 was inhibited by 16.10, 3.42, 1.89, 14.72 and 16.67 % compared to the control at F100, B100, B50, L100 and L50, respectively (Fig. 2). On the other hand, it was stimulated by 6.03 and 21.46 % over the control under F50 and A100, respectively (Fig. 2). In DBW-17, root length was stimulated by all the treatments except L50, where it was inhibited by 2.31 % over the control (Fig. 2). The stimulation was 4.33 to 37.32 % compared to the control and the maximum increase was in treatment of A100 (Fig. 2).

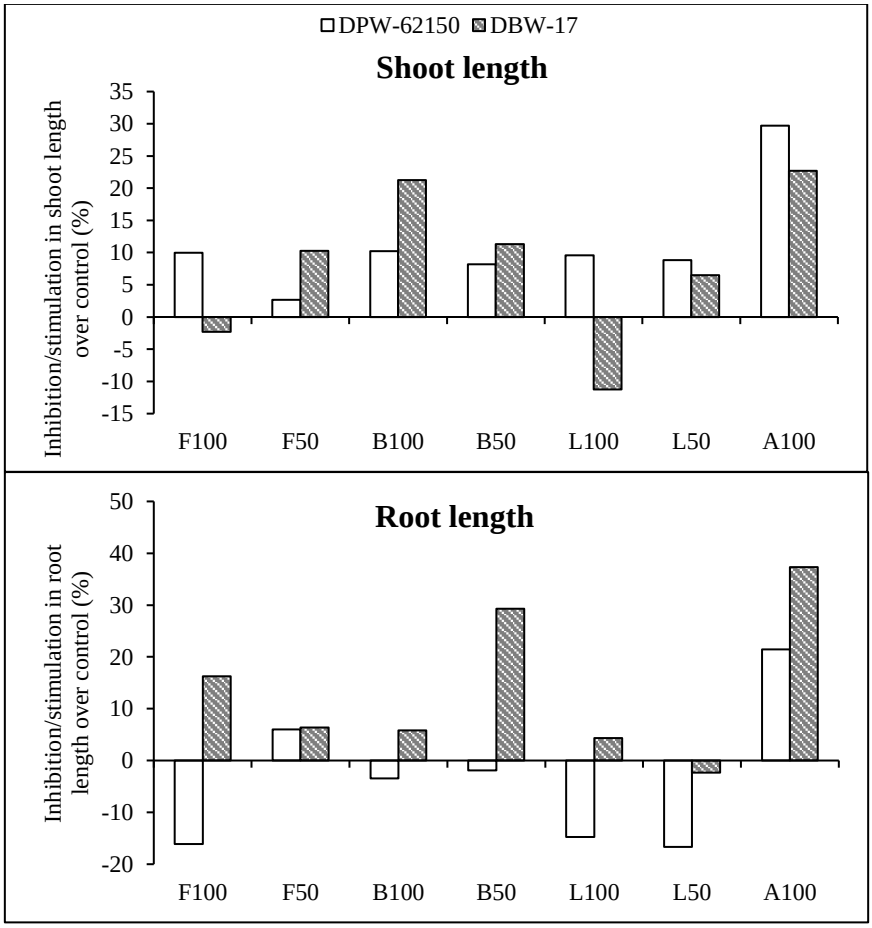


Figure 2. Effects of abscised plant parts of *Terminalia arjuna* on shoot length and root length in 7-day-old seedlings of *Triticum aestivum* variety DPW-62150 and DBW-17. Data presented as inhibition/stimulation in different treatments over control. Treatments: F100: Fruit powder (20.53 g $pot^{-1}$); F50: Fruit powder (10.26 g $pot^{-1}$); B100: Branch powder (18.04 g $pot^{-1}$); B50: Branch powder (9.02 g $pot^{-1}$); L100: Leaf powder (29.87 g $pot^{-1}$); L50: Leaf powder (14.93 g $pot^{-1}$); and A100: Mixture of fruit, branch and leaf powder (34.26 g $pot^{-1}$)

**Dry weight :** Dry weight of the treated seedlings of DPW-62150 was inhibited by 7.31, 12.82, 11.39 and 11.39 % over the control under F100, F50, B100 and B50, respectively, whereas it was stimulated by 2.22, 3.29 and 26.05 % over the control under L100, L50 and A100, respectively (Fig. 3). On the contrary, dry weight in DBW-17 was stimulated remarkably under all the treatments in the range of 15.8-32.35 % over the control, with the maximum stimulation in the seedlings treated with L50 and A100 (Fig. 3).

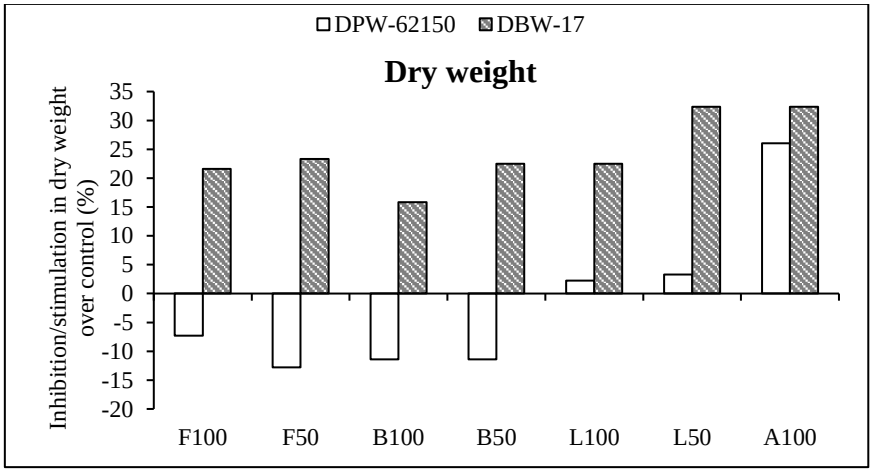


Figure 3. Effects of abscised plant parts of *Terminalia arjuna* on dry weight of 7-day-old seedlings of *Triticum aestivum* variety DPW-62150 and DBW-17. Data presented as inhibition/stimulation in different treatments over control. Treatments: F100: Fruit powder (20.53 g $pot^{-1}$); F50: Fruit powder (10.26 g $pot^{-1}$); B100: Branch powder (18.04g $pot^{-1}$); B50: Branch powder (9.02 g $pot^{-1}$); L100: Leaf powder (29.87 g $pot^{-1}$); L50: Leaf powder (14.93 g $pot^{-1}$); and A100: Mixture of fruit, branch and leaf powder (34.26 g $pot^{-1}$)

**Vigour Index:** The vigour index of the treated wheat seedlings was inhibited with respect to control under F50 (by 6.81 %), L100 (by 14.00 %) and L50 (by 5.03 %) in DPW-62150 and under F100 (by 3.21 %), L100 (by 14.52 %) and L50 (by 5.34 %) in DBW-17 (Fig. 4). On the other hand, it was stimulated over control under F100 (by 0.43 %), B100 (by 7.24 %), B50 (by 4.14 %) and A100 (by 22.43 %) in DPW-62150 and under F50 (by 15.87 %), B100 (by 22.64 %), B50 (by 25.10 %) and A100 (by 28.40 %) in DBW-17 (Fig. 4). Compared to the control, the Tolerance Index in DPW-62150 was inhibited by 3.43-22.59 % under all the treatments except F50 (stimulated by 6.02 %) and A100 (stimulated by 21.46 %), whereas in DBW-17, it was stimulated by 4.33-37.32 % under all the treatments except L50 (inhibited by 2.32 %) (Fig. 4).

**Biochemical parameters:**

(i). **Chlorophyll :** Total chlorophyll in the seedlings of DPW-62150 was negatively affected compared to the control when exposed to F100 (by 4.78 %), B50 (by 8.43 %), L100 (by 7.35 %) and L50 (by 5.30 %), but positively affected compared to the control upon the treatment of F50 (by 7.76 %), B100 (by 11.78 %) and A100 (by 1.98 %) (Fig. 5). However, in DBW-17, total chlorophyll was only positively affected compared to the control showing a stimualtion in the range of 3.83-24.99 %, with the maximum increase observed in the seedlings treated with B50 (Fig. 5).

(ii). **Nitrogen :** Nitrogen in the seedlings of DPW-62150 was decreased over the control under all the treatments within an inhibition range of 1.03-12.43 % except in case of B50, where it was stimulated by 4.77 % (Fig. 5). However in contrast, nitrogen in the seedlings of DBW-17 was enhanced over the control under all the treatments within a stimulation range of 2.60-9.25 % except in case of B100, where it was inhibited by 19.28 % (Fig. 5).

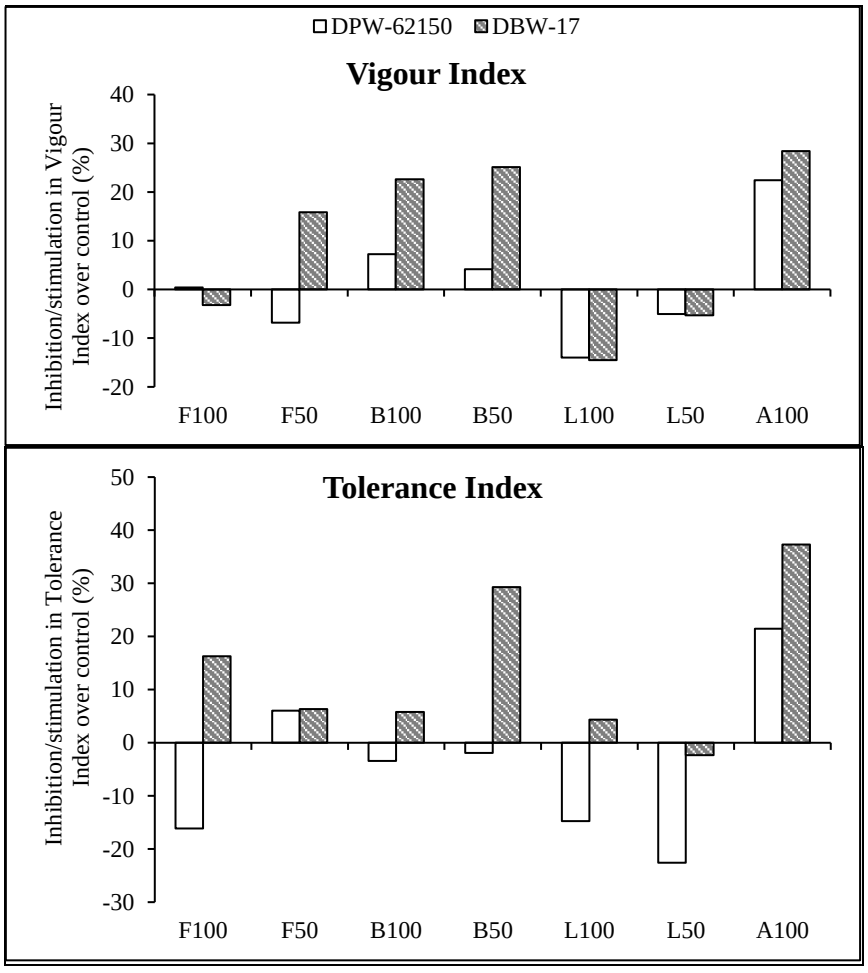


Figure 4. Effects of abscised plant parts of *Terminalia arjuna* on Vigour Index and Tolerance Index of *Triticum aestivum* variety DPW-62150 and DBW-17. Data presented as inhibition/stimulation in different treatments over control. Treatments: F100: Fruit powder (20.53 g $pot^{-1}$); F50: Fruit powder (10.26 g $pot^{-1}$); B100: Branch powder (18.04g $pot^{-1}$); B50: Branch powder (9.02 g $pot^{-1}$); L100: Leaf powder (29.87g $pot^{-1}$); L50: Leaf powder (14.93 g $pot^{-1}$); and A100: Mixture of fruit, branch and leaf powder (34.26 g $pot^{-1}$)

(iii). **Organic carbon :** In comparison to the untreated seedlings, organic carbon in DPW-62150 was decreased by 6.60, 1.50, 20.37, 6.50, 9.30 and 11.32 % when subjected to F100, F50, B100, B50, L100 and A100, respectively, whereas it was enhanced by 9.46 % under L50 (Fig. 5). Likewise, F100, B100, L100, L50 and A100 decreased the organic carbon in DBW-17 by 5.85, 24.91, 25.48, 0.27, 4.35 %, respectively, over the control and F50 and B50 enhanced it by 0.36 and 0.18 %, respectively over the control (Fig. 5).

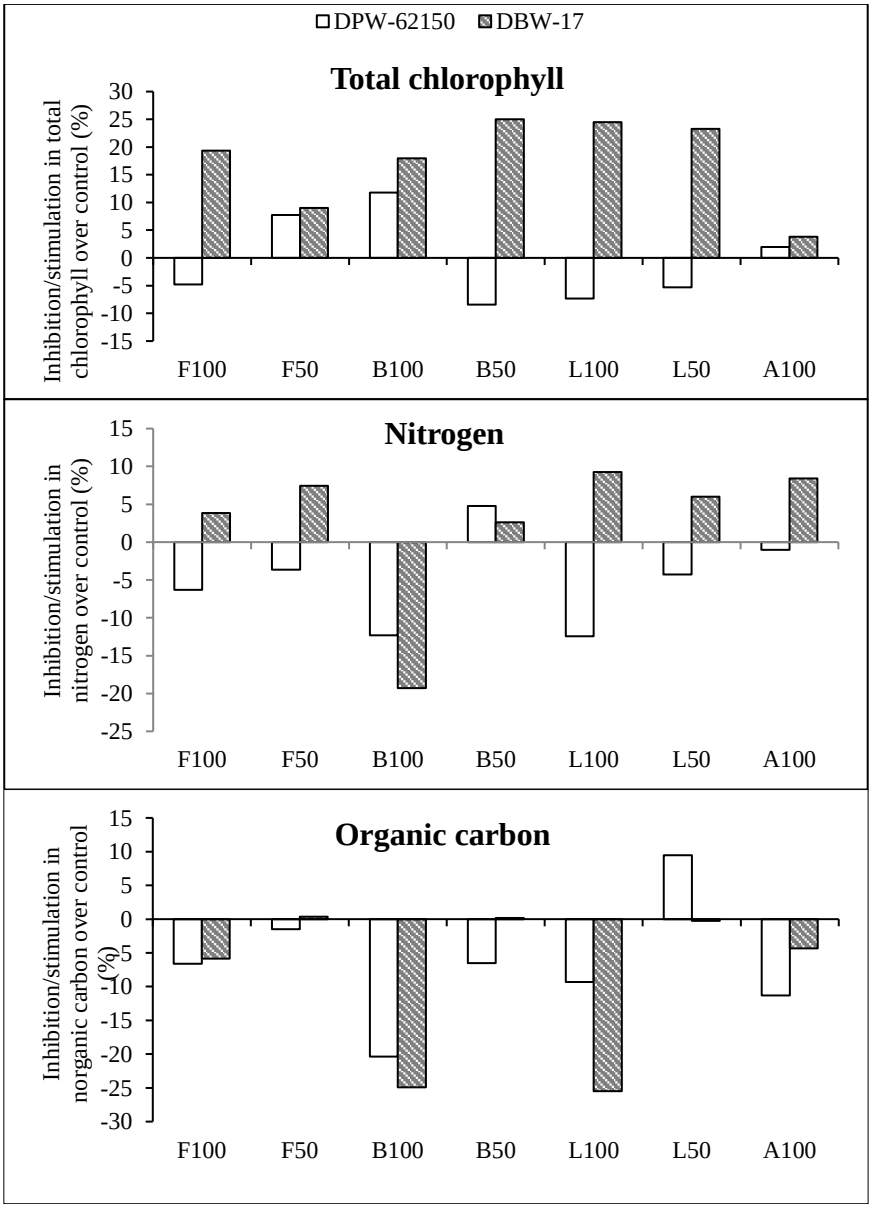


Figure 5. Effects of abscised plant parts of *Terminalia arjuna* on total chlorophyll, nitrogen and organic carbon in 7-day-old seedlings of *Triticum aestivum* variety DPW-62150 and DBW-17. Data presented as inhibition/stimulation in different treatments over control. Treatments: F100: Fruit powder (20.53 g $pot^{-1}$); F50: Fruit powder (10.26 g $pot^{-1}$); B100: Branch powder (18.04 g $pot^{-1}$); B50: Branch powder (9.02 g $pot^{-1}$); L100: Leaf powder (29.87 g $pot^{-1}$); L50: Leaf powder (14.93 g $pot^{-1}$); and A100: Mixture of fruit, branch and leaf powder (34.26 g $pot^{-1}$)

Although both the varieties differed in the intensity of response to the treatments, the direction of response was nearly consistent. DBW-17 performed better under most of the treatments as compared to DPW-62150. It has been often observed that bioassays show differential and species-specific response towards allelochemicals (9,12,27,32). In some species, a particular concentration of allelochemicals may not reach their threshold level, but for the others the same proportion of allelochemicals may be sufficient for triggering a response (33). Moreover, the defence system of the recipient plant is also crucial for determining its sensitivity towards the allelopathic stimulus (5). Different treatments (F100, F50, B100, B50, L100, L50, and A100) were observed to induce a variable response on both the varieties. Seed germination was inhibited by fruits, leaves and the mixture of all plant parts; however, the plant material obtained from branches promoted the germination in both DPW-62150 and DBW-17. Likewise, seedling growth (root length, shoot length, and dry weight), Vigour Index and Tolerance Index were selectively inhibited by the plant material obtained from fruits, branches and leaves but significantly promoted by the mixture of all plant parts. On the contrary, total chlorophyll, nitrogen and organic carbon in the varieties of *T. aestivum* were both upregulated and downregulated in an unspecific pattern.

**Gas Chromatography and Mass Spectrometry (GC-MS) analysis of *T. arjuna***

GC-MS analysis of fresh leaf material and leaf litter revealed the presence of several plant secondary metabolites, which are previously reported as potent growth inhibitors (3,18,34). A total of 49 compounds were identified in the GC-MS analysis, of which 28 were present in the chloroform extracts of fruit powder, 28 in the branch powder and 33 in the leaf powder (Table 2). Fifteen compounds were common to all plant parts, i.e., 1,1,2,2-tetrachloroethane, 1,1,2,3,3-pentachloropropane, 1,2-benzenedicarboxylic acid, 1-dodecanol, 2-chlorobutanoyl chloride, 2-hydroxyhexadecanoic acid, 2-methyl-hexacosane, 4-propylbenzaldehyde, docosane, eicosane, nonadecane, octadecane, pentadecane, tetradecane and tricosane (Table 2).

Allelopathic effects are measured in terms of release of specific chemical compounds (plant secondary metabolites) by a plant specie that either suppresses or stimulates the growth of associated plant species (23). The chemical compounds involved in the phenomenon are known as allelochemicals, which mainly include phenolics, flavonoids, alkaloids, terpenoids, tannins, steroids, saponins, cyanogenic glycosides, and plant growth regulators (21). These metabolites are stored in different parts of the plants such as leaves, fruits, seeds, flowers, pollens, roots, and stem (14); however, leaves are generally the most potent source of allelochemicals (20). Allelochemicals are released into the surrounding environment via leachation, volatilization, residue degradation, or root exudation (17). Certain species use allelochemicals to inhibit the co-occurring vegetation by interfering with their growth and development to establish their own monocultures (6,11). In agroecosystems, several woody plants exhibit negative allelopathic influence on the companion crops, by affecting their germination, growth and physiology. For example, studies have shown the inhibitory effects of *Mangifera indica* L. on *Oryza sativa* L.; *Azadirachta indica* A.Juss. on *T. aestivum* L. and *Pennisetum* spp.; *Acacia* spp. on *T. aestivum* and *Pennisetum* spp.; *Leucaena leucocephala* (Lam.) de Wit on *Zea mays* L. and *O. sativa*; *Eucalyptus* spp. on *T. aestivum*, *Brassica* spp., *Cicer arietinum* L., *Z. mays*, and *Sorghum bicolor* (L.) Moench.; *Populus* spp. on *Saccharum officinarum* L. and

*T. aestivum*; and *Juglans regia* L. on *Brassica rapa* L., *Eleusine coracana* (L.) Gaertn., and *Setaria italica* (L.) P. Beauv. (15).

Table 2. Putative allelochemical compounds identified by Gas Chromatography-Mass Spectrometry (GC-MS) analysis in the chloroform extracts of abscised plant parts (fruits, branches, leaves) of *Terminalia arjuna* as determined.

| S. No. | Name | Fruits | Branches | Leaves |
|---|---|---|---|---|
| 1. | 1,1,2,2,3,3-hexachloropropane | + | - | - |
| 2. | 1,1,2,2,3-pentachlorocyclopropane | - | - | + |
| 3. | 1,1,2,2-tetrachloroethane | + | + | + |
| 4. | 1,1,2,3,3-pentachloropropane | + | + | + |
| 5. | 1,2-benzenedicarboxylic acid | + | + | + |
| 6. | 1,2-dichloro-2-methylpropane | + | - | - |
| 7. | 1,2-dichlorobutane | - | - | + |
| 8. | 1-chlorooctadecane | + | + | - |
| 9. | 1-dodecanol | + | + | + |
| 10. | 2,6,10,14,18,22-tetracosahexaene | - | + | + |
| 11. | 2,6,10,14-tetramethylheptadecane | + | - | - |
| 12. | 2,6,11-trimethyldodecane | - | - | + |
| 13. | 2-bromotetradecane | + | - | - |
| 14. | 2-chlorobutanoyl chloride | + | + | + |
| 15. | 2-ethyl-1-decanol | - | - | + |
| 16. | 2-hydroxyhexadecanoic acid | + | + | + |
| 17. | 2-isopropyl-5-methyl-1-heptanol | + | - | - |
| 18. | 2-methyleicosane | - | + | - |
| 19. | 2-methylhexacosane | + | + | + |
| 20. | 2-methylnonadecane | + | - | - |
| 21. | 3,5-cycloheptadien-1-one | - | - | + |
| 22. | 3,7-dimethyldecane | - | + | + |
| 23. | 3,7-dimethylundecane | - | - | + |
| 24. | 3-chloro-3-methylhexane | - | + | - |
| 25. | 4-methylhexadecane | + | - | - |
| 26. | 4-propylbenzaldehyde | + | + | + |
| 27. | 5-methyltetradecane | - | + | - |
| 28. | 6,9-dimethyltetradecane | - | - | + |
| 29. | 9-octylheptadecane | - | - | + |
| 30. | Decyl acetate | - | - | + |
| 31. | Docosane | + | + | + |
| 32. | Dotriacontane | - | + | + |
| 33. | Eicosane | + | + | + |
| 34. | Heptacosane | - | + | + |
| 35. | Heptadecane | + | + | - |
| 36. | Hexacosane | - | - | + |
| 37. | Hexadecane | + | - | + |

+ : Pesence ; -: Absence

However, the allelopathic effects of a plant specie depends upon the quality and bioactive quantity of allelochemicals and the intensity of the effects may vary with specificity and efflux-matrix-influx compatibility (17,29). In addition, certain allelochemicals are more potent and can cause greater inhibitory effects (8). Therefore,

differential production of allelochemicals by fruits, branches, and leaves might have been responsible for the variable impact on the growth parameters. Furthermore, in case of mixture of all plant parts, a synergistic effect of allelochemicals might have been in play. Synergistic effects of chemicals are usually very different from their individual effects, and sometimes can result in additive or entirely contrary outcomes (26).

## CONCLUSIONS

The mixture of all the plant parts of *T. arjuna* stimulated most of the studied parameters viz., shoot length, root length, fresh weight, dry weight, tolerance index, vigour index and chlorophyll, nitrogen and carbon content in *T. aestivum* varieties DPW-62150 and DBW-17. The study suggests that *T. aestivum*, particularly variety DBW-17, can be successfully intercropped with *T. arjuna*. However, the benefits of agroforestry depend on multiple factors such as orientation and number of trees, the interactive effects of which may vary under field conditions. Therefore, further field studies should be undertaken on a wider scale to validate the results of the present study.

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## DECLARATION

We declare that all authors of this Ms. have made substantial contributions. We did not exclude any author who substantially contributed to this Ms. We have followed our ethical norms established by our respective institutions.

## CONFLICT OF INTEREST

The authors announce that they have no conflict of interest.

## ETHICAL APPROVAL

The authors declare that the study was carried out following scientific ethics and conduct. However, this study did not involve any use of animals, hence no ethical approval has been obtained from the concerned committee.

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## PUBLISHER NOTE