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RESEARCH PAPER

Allelopathy Index: a new mathematical assessment method for allelopathy studies

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A B S T R A C T:

A lab bioassay was conducted in Agricultural Engineering Sciences College labs to study the allelopathic influence of wild oat (***Avena fatua* L**.) different plant parts shoot, root and seeds aqueous extracts with five concentrations (0, 25%, 50%, 75% and 100%) on three plant species Lettuce, Onion and Tomato seeds. Results indicated significant effect on all studied data, germination percentage, inhibition of germination, radicle length (cm); plumule length(cm); radicle dry weight, plumule dry weight; total seedlings dry weight (mg); radicle and plumule growth inhibition. The best bioassay plant was lettuce seeds for using as indicator in allelopathy studies. The main goal of the study was proposing five mathematical equations to indicate allelopathy index, the best two equations were chosen according to their best manipulation and demonstration based on total seedlings dry weight.

KEY WORDS: Allelopathy Index, Concentration dependent, Mathematical Equations.
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1.INTRODUCTION:

Interference between plants divided to two ecological phenomenon competition and allelopathy, the first takes place for environmental resources such as light, nutrient, moisture and space, while in allelopathy phenomenon donor plants excrete chemicals to suppress the growth of plants in vicinity (Ali, 2001). There are many studies that tried to separate between both phenomenon's that may influence plant life either by reducing essential growth needs or by producing chemical compounds that finally both alter the recipient plant metabolism and growth (Fernandez et al., 2016, He et al., 2012, Ali and Sakri, 2010).

Allelopathy interactions may include both harmful or beneficial biochemical relationship between plants and surrounding organisms (Dias et al., 2017).

Plants are non-motile creatures so they developed the ability to adapt their environmental fluctuation periods through different techniques. Plant plasticity which, is defined as (plants ability to adapt to or cope with changes in its environment), it is one of the methods that plants pursued to face their macro and micro environment changes (Karban, 2008). Plants have acquired the capability of biosynthesizing different bioactive natural compounds with definite role to withstand unfavorable environmental challenges (Agrawal et al., 2002, Ali and Aziz, 2002).

The considerable progress of allelopathy studies in different aspects such as crop production, weed management and the importance of sustainable agriculture leads to a huge improvement in food production and it minimizes the environmental damages by establishing eco-friendly agricultural systems (An et al., 2008). Different bioassay techniques were used in allelopathy researches to indicate the effect of different levels of concentration of either water (aqueous) or alcoholic extract of different plant parts (seed, shoot and root) on some selected plant seeds, then quantitative parameters will be recorded to

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interpret the situation, most times the effect may be concentration dependent while some times it will be stimuli in low concentrations and inhibitor in high concentrations or vis versa (Ercoli et al., 2007, Rejila and Vijayakumar, 2011).

Analysis and interpretation of allelopathy studies focuses on plants chemical interaction of donor plant on recipient plant through different characteristics parameters, many attempts had been carried out to present or suggest mathematical models for data manipulation in order to clarify allelopathical effects (An et al., 2002, An et al., 2008, Liu et al., 2003, Pal et al., 2009, Liu et al., 2011, Williamson and Richardson, 1988). Mathematical equations were presented to illustrate the allelopathic effects on recipient plants depending on stimulation and inhabitation effects according to extract concentration as in equation (1) which were proposed by (An et al., 1993) where p is the biological response to the allelochemical and S is the stimulatory or I the inhibitory effect. There was also an attempt to indicate the effect of an allelochemical in the environment as in equation (2) depending on the system of production , transformation and decomposition of allelochemicals (An et al., 2003) where AE is the amount of the allelochemical in the environment and K1 is the rate of allelochemicals release per day and K2 is the rate constant of an allelochemical degradation per day.

$$\boldsymbol{P = 100 + S - I} \qquad \ldots\ldots\ldots(\mathbf{1})$$

$$\mathbf{AE} = \frac{\mathbf{K1\ f\ (t)}}{\mathbf{K2 - K1}}\left(\mathbf{e^{-K1\ t} - e^{-K2\ t}}\right) \qquad \textbf{..... (2)}$$

(Liu et al., 2003) proposed a new mathematical equation based on the relationship between the allelochemical dose and the response of the recipient organism and they assumed that the response will be non-linear as in equation (3) where E(D) is the effect of allelochemical, D is the dose, R is the response and RC is the response in control treatments.

$$\boldsymbol{R = RC + E(D)} \qquad \ldots\ldots\ldots\ldots(\mathbf{3})$$

In this study, some mathematical equations will be presented on the base that allelopathy is regarded as abiotic environmental stress where the donor plant alters the target plants growth and development by producing allelochemical compounds (Pedrol et al., 2006). Data from this work and other papers will be analyzed to suggest the most suitable equation for allelopathy studies to indicate the best allelopathy index. Our proposed equations were based on seedling's dry weight which we think, is the most reliable data for plant growth. We could estimate allelopathy index (AI) on recipient plants as in equation (4) where (DWc) is the dry weight of control treatments, (DWt) is dry weight of treatment. Also allelopathy index (AI) could be estimated according to equation (5) or (6) where (DWgm) is the mean dry weight for all treatments or as in equation (7) and (8) where SDWt is seedlings dry weight in treatment and SDWc is the seedlings dry weight in control. Another equation will be proposed in this study according to the linear relationship between the extract concentration and the response of the recipient plant (8) where (ymax) is y when C = 0, while Co is C at which y=0 and b can be estimated according to the slope of the relative ship between ln (y/ymax) on ordinate and ln (1-Co/C) on abcissia.

$$\mathbf{AS} = \mathbf{DWc - DWt} \qquad \ldots\ldots\ldots\ldots(\mathbf{4})$$

$$\mathbf{AI} = \mathbf{1} - \left(\frac{\mathbf{DWc - DWt}}{\mathbf{DWgm}}\right) \qquad \ldots\ldots\ldots\ldots\ldots(\mathbf{5})$$

$$\mathbf{AI} = \left(\frac{\mathbf{1} - \left(\frac{\mathbf{DWt}}{\mathbf{DWc}}\right)}{\mathbf{1} - \left(\frac{\mathbf{DWmt}}{\mathbf{DWmc}}\right)} \right) \quad \ldots\ldots\ldots\ldots (6)$$

$$\boldsymbol{AI} = \left(\mathbf{1} - \frac{\boldsymbol{SDWt}}{\boldsymbol{SDWc}}\right) \times \mathbf{100} \quad \ldots\ldots\ldots\ldots (7)$$

$$\boldsymbol{AI} = \boldsymbol{ymax}\left(\mathbf{1} - \frac{\boldsymbol{C}}{\boldsymbol{Co}}\right)^{\boldsymbol{b}} \quad \ldots\ldots\ldots\ldots (8)$$

The selected donor plant for this study was wild oat (***Avena fatua*** L.) which was previously reported to cause allelopathic effect on recipient plants (Schumacher et al., 1983, Fragasso et al., 2012, Fay and Duke, 1977). The main goal of the study is proposing five mathematical equations to indicate the best interpretation for allelopathy index.

2.MATERIALS AND METHODS:

The study consists of a completely randomized factorial experiment of three treatments with three replications, first three recipient plant species of recipient plants (Lettuce, Tomato and Onion), second three wild oat plant parts aqueous extract (shoot, root and seeds), third five extract concentration levels (zero, 25, 50, 75 and 100%) zero concentration was considered as control.

2.1Plant Samples: Wild oat plants were collected from the grdarasha field of agricultural engineering sciences college during 2017-2018 agricultural season and separated to three parts (Root, shoot and seeds). First plant parts were cut to small 2-3cm peace's, next it was air dried in a shade place, then it was milled by electrical mill finally it was kept in dark plastic jars and put in () cooler machine -20°C till use.

2.2 Extract Preparation: first 10g of wild oat plant parts and 100ml of distilled water were put in dark bottles, next the bottles were placed in a shaker 120RPM for 24 hours. Then the aqueous solutions passed through four layers of cheese-cloth after that it was filtered by whatman filter paper #1. The final extract aqueous extract was considered as (100 % crude solution), finally different concentrations were prepared as 25, 50, 75 and 100% from the crude extract by adding distilled water, while distilled water was considered as control treatment (Sisodia and Siddiqui, 2010, Ali and Maulood, 2011, Ali et al., 2012).

2.3 Bioassay: seeds of Lattuce (*Lactuca sativa* L.), tomato (*Solanum lycopersicum* L.) and Onion (*Allium cepa* L.) were selected for this study due to their sensitivity and use in plant hormone bioassays (Macías et al., 2000, Sampietro, 2009). First twenty-five seeds of each species were placed between two sheets of whatman filter paper #1 in 9 cm petri-dishes next 8ml of the studied concentrations of aqueous extracts of three wild oat plant parts (shoot, root and seeds) were added to each petri-dish, then each petri-dish were sealed with para-film and placed in a growth chamber under 22 -24°C. finally the experiment was finished after 10 days where seedlings were collected.

2.4 Recorded Data: The recording data were germination rate; radicle length (cm); radicle dry weight (g); plumule length(cm); plumule dry weight (g); seedlings dry weight (mg), inhibition of germination, radicle and plumule growth inhibition measured according to equations shown below (Oliveira et al., 2013, Norsworthy, 2003, Jiang and Lafitte, 2007, Ali and Aziz, 2002).

$$\textbf{Germination } \% = \frac{GS}{TTS} \times 100 \quad \text{..... (9)}$$

$$\textbf{IOG } \% = \frac{GPC - GPT}{GPC} \times 100 \quad \text{... ... . (10)}$$

$$\textbf{RGI or PGI } \% = \left(1 - \frac{WUS}{WNS}\right) \times 100 \quad \text{... ... ... (11)}$$

Where GS = germinated seeds, TTS = Total tested seeds, IOG= Inhibition of germination, GPC= germination percentage of control, GPT= germination percentage of treatment, RGI= radicle growth inhibition, PGI= plumule growth inhibition, WUS= dry weight under stress, WNS= dry weight under non stress conditions.

2.5 Allelopathy Index Equations: proposed equations (4), (5), (6), (7) and (8) were used for indicating the most suitable mathematical equation for studying allelopathical plant relationships.

2.6 Statistical Analysis: all recorded data were subjected to standard analysis of variance and means were compared using Duncan Multiple Range Test (DMRT) at 5% of probability using SPSS computer analysis version (Field, 2013, Weinberg and Abramowitz, 2008).

3. RESULTS AND DISCUSSION

Results of this study could divided to the three main factors and the interactions between them as will be summarized below.

3.1. The effect of tested plant species on germination and some seedling growth characteristics: Table (1) indicates the significant effect of aqueous extracts of wild oat on all recorded data of the three tested plant species in this study. Whereas the highest germination percentage, Plumule and radicle length, Plumule, radical and total dry weight were 95%, 3.81cm, 2.83 cm 1.24g ,0.66 g, 1.91g respectively were recorded with tomato seedlings and the lowest data for mentioned characteristics were recorded for lettuce plants in germination percentage, radicle length, radicle and total dry weight 83.56%, 0.78cm, 0.07g and 0.51g respectively, while onion seedling where at lowest levels for Plumule length and Plumule dry weight 3.08cm and 0.42 g respectively. Data of inhibition of germination, Plumule and radicle growth inhibition indicates the significant differences between the three plant species response to the aqueous extracts of wild oat whereas for inhibition of germination the highest value was 16.44% with lettuce seedlings and the lowest was 4.27% in tomato seeds, while highest data of Plumule and radicle growth inhibition were recorded with tomato seedlings 25.44% and 72.89% respectively, but the lowest data values for both was recoded with lettuce seedlings. This disparity between studied plants species response may be shown because of their genetic variation (Abd-ElGawad et al., 2020, Ali, 2016).

3.2. The Effect of Plant Parts Aqueous Extracts on Germination and Some Seedling Growth Characteristics: The effect of shoot, root and seeds aqueous extracts of wild oat cased significant differences on all recorded data except data of roots dry weight (table- 2). The highest values for germination percentage, Plumule and radicle length, Plumule and total seedling dry weight were 95.02%, 4.62(cm), 2.37(cm), 0.77(g) and 1.05(g) respectively which were observed with root aqueous extracts. Lowest data for germination percentage 84.89% was observed with shoot aqueous extracts. Lowest levels for Plumule and radicle length, Plumule and total dry weight were 2.20 (cm), 0.99(cm), 0.60 (g) and 0.85 (g) respectively reported with seeds aqueous extracts of wild oat.

Inhibition of germination was at highest level with shoot extracts 15.11% and lowest data was 4.98 % recorded with root extracts. Records of Plumule and radicle growth inhibition where at the pick 32.12 % and 66.29% respectively with seeds aqueous extracts and at their minimum levels 4.63% of Plumule growth inhibition under the impact of root extracts and 54.92% for radicle growth inhibition treated with shoot extracts. It seems that shoot plant parts had stronger allelopathic impact comparing to both root and seeds extracts which may be due to its high content of phytochemical compounds which may be photosynthesis byproducts which may kept in cell as compartments or stored in cell vacuoles (Kamal, 2011, Sodaeizadeh et al., 2009).

3.3. The Effect of Aqueous Extracts Concentration levels on Germination and Some Seedling Growth Characteristics: Table-3 indicates the significant effect of concentration levels on all recorded data, highest values for germination percentage, plumule and radicle length, plumule, radicle and total dry weight were 99.85%, 5.40(cm), 3.20(cm), 0.90 (g), 0.96(g) and 1.86 (g) respectively where observed with control treatments. Lowest records were observed with the highest concentration level 100% these data declare the concentration dependent allelopathic effect for aqueous extracts (Ali, 2016, Ali and Aziz, 2002). Data of inhibition of germination, plumule growth inhibition, radicle growth inhibition where in harmony with concentration levels which means they were in lowest levels in control treatments, while they were elevated with highest concentration levels in this study. The phenomenon of utmost impact with higher concenrtation may be due to accumulation of allelochemicals in higher extract concentrations as indicated by (El-Rokiek and Eid, 2009, Bing-Yao et al., 2006).

3.4. The Combination Effect of Tested Plant Species and Wild Oat Plant Part Aqueous Extracts on Germination and Some Seedling Growth Characteristics: The effect of interaction of plant species and extract parts significantly affected all recorded data except radicle dry weight (Table-4). The maximum value for germination percentage was 98.40% in tomato seeds treated with wild oat seed extracts, while minimum value was 73.33% when lettuce seeds treated with wild oat seeds extracts. The peak data of plumule length were (5.12 cm) observed in two sets in tomato seedlings treated with wild oat root extracts and onion seedlings treated with root extracts, while the least value was 1.64 (cm) when onion seedling that was treated with wild oat seed extracts. Tomato seeds when treated with wild oat root extracts had longer radicle length 4.71 (cm) but when lettuce seeds treated with shoot extracts it resulted the shortest radicle length 0.57 (cm). plumule and seedlings total dry weight were at highest levels 1.42 (g) and 2.13(g) respectively when tomato seeds treated with wild oat shoot extracts, while lowest values 0.29 (g) and 0.37 (g) respectively by treating onion seeds with wild oat seed extracts. Inhibition of germination was at highest level 26.67% in lettuce seeds which treated with wild oat seed extracts and in lowest level 3.47% when onion seeds treated with wild oat seed extracts. Records of Plumule and radicle growth inhibition where at the peak 47.30 % and 70.86 % respectively with onion seeds treated with wild oat seed aqueous extracts and at their minimum levels -16.60 % for Plumule growth inhibition when onion seeds treated with wild oat root extracts and 44.41% for radicle growth inhibition for lettuce seeds which treated with wild oat shoot extracts. The goal of studying this combination effect is to indicated the most sensitive plant species that bioassayed under the impact of different wild oat plant part aqueous extractions, it was obvious that genetic variation was the main cause for bioassayed test plants sensitivity to different wild oat plant part extracts and the allelochemical content in wild oat plant parts which had been reported that five allelochemical compounds had been isolated from the shoot parts of wild oats (Liu et al., 2016).

3.5 The Combination Effect of Tested Plant Species and Wild Oat Plant Part Aqueous Extracts on Germination and Some Seedling Growth Characteristics: The combined effect of plant species and wild oat plant part extract caused significant differences on all recorded data as shown in table (5). 100% germination percentage were recorded with lettuce and tomato seedlings under control treatments, while lowest germination percentage was 60.44% in lettuce seeds under 100% concentration of wild oat extracts. The higher plumule length was 7.00 (cm) observed with onion seedlings in control treatment, while the lowest plumule length was 1.58 (cm) in onion seedlings under 100% extract concentration. Maximum data of radicle length was 5.87 (cm) in tomato seedlings treated with distilled water (control), meanwhile minimum data was 0.30 (cm) with onion seedlings under 100% extract concentration. The plumule dry weight peak was 1.67(g) with tomato seedlings in control treatment, while tiniest value was 0.33 (g) in onion seedlings under 100% extract concentration. The radicle dry weight peak was 2.47 (g) with tomato seedlings in control treatment, while lowest value was 0.01 (g) in lettuce seedlings under 100% extract concentration. The highest seedlings total dry weight was 4.14 (g) in tomato under control treatments, while lowest value was 0.38 (g) when lettuce seeds where treated with 100% extract concentration. Inhibition of germination percentage parameters in table (5) indicates highest value in lettuce seeds treated with 100% extract concentration and lowest values where 0.00% in control treatments of lettuce and tomato seeds. Plumule growth inhibition was at highest level 42.35% with tomato seedlings under 100% extraction concentration, while lowest value was -5.70% in lettuce seeds under 25% extract concentration. Highest radicle growth inhibition was 92.37% in tomato seeds under 100% extract concentration, meanwhile lowest values were 0% in two cases of lettuce and onion seeds under control treatments. It had been reported that shoot parts of wild oat contain five allelochemical compounds (syringic acid, tricin, acacetin, syringoside, and diosmetin)(Liu et al., 2016).

3.6 The Combination Effect of Wild Oat Plant Part Aqueous Extracts and The Extract Concentration on Germination and Some Seedling Growth Characteristics: The combination effect of plant part extract and extract concertation imposed significant effect on all recorded data except radicle dry weight (table-6). The germination percentage were in highest levels 100% in control treatments for root and seed aqueous extracts, while lowest value was 65.33% in shoot parts highest concentartion100%. The highest record for plumule length was 5.42 (cm) with the control treatment of shoot aqueous extracts, while the minimum value 0.51 (cm) was observed in seed extracts with 100% concentration. Radicle length were at its highest levels 3.20 (cm) in control treatments for the three plants parts (shoot, root and seeds), meanwhile the lowest level 0.22 (cm) with seeds extracts in 100% concentration. Plumule and total seedlings dry weight were at the peak 0.90 (g) and 1.86 (g) respectively for the three plant parts aqueous extracts (shoot, root and seed) with control treatments, the minimum value for Plumule and total seedlings dry weight were 0.34 (g) and 0.39 (g) respectively in seeds extracts under the highest concentration 100%.

The data of inhibition of germination was at highest level 34.67% in shoot extracts under maximum concentration level 100% and in lowest level 0% in root and seeds control treatments. Records of Plumule and radicle growth inhibition where at the peak 60.68 % and 94.14 % respectively with seeds extract under 100% concentration and at their minimum levels 0% in control treatments for the three plant parts (shoot, root and seed) extracts. It was reported that aerial parts (shoot) of wild oat contains higher amounts of allelochemicals when compared with root or seeds (Liu et al., 2016). The allelopathic effect was concentration dependent (Ali and Aziz, 2002).

3.7 The Triple Effect of tested Plant Species, Wild Oat Plant Part Aqueous Extracts and The Extract Concentration on Germination and Some Seedling Growth Characteristics: The triple effect was significant on all reported data except radicle dry weight (Table-7). The highest germination percentage 100% were reported with lettuce seeds when treated with control treatment for shoot, root and seed parts of wild oat plants and also 25% of root aqueous extracts, while for onion seeds control of root and seeds extracts and also concentration of 25% of root aqueous extracts and 50% of seeds extracts, whereas for tomato seeds for control treatments of shoot, root and seeds of wild oat extracts beside 25 and 75% of seeds aqueous extracts. The lowest value of germination percentage was 37.33% recorded with seeds aqueous extracts of wild oat under 100% concentration. Data of plumule length was at highest level 7.07 (cm) in the triple effect of onion tested seeds treated with control of shoots aqueous extracts, while lowest value was 0.19 (cm) reported in the interaction between onion seeds treated with wild oats seeds aqueous extracts with 100% concentration. Radicle length data indicated highest levels 5.87 (cm) with the combination between tomato tested seeds under the three plant parts (shoot, root and seeds) aqueous extracts with control treatments, meanwhile lowest observed data was 0.09 (cm) when onion seeds treated with seeds aqueous extracts in 100% concentration. Plumule dry weight were at the peak 1.67 (g) with the triple effect of tomato tested seeds treated with control of the three wild oat aqueous extracts while it was at minimum level 0.08 (g) when onion tested seeds treated with wild oat seeds aqueous extract with 100% concentration. Seedling total dry weight were at the highest value 4.14 (g) with the triple effect of tomato tested seeds treated with control of the three wild oat aqueous extracts while it was at lowest level 0.10 (g) when onion tested seeds treated with wild oat seeds aqueous extract

with 100% concentration. Inhibition of germination percentage parameters in table (7) indicates highest value 37.33% in lettuce seeds treated with wild oats seeds extracts with the 100% concentration and lowest values where 0.00% in control treatments of lettuce, onion and tomato seeds beside lettuce treated with root extracts with 25% concentration, onion seeds treated with wild oats root extracts with the concentration 25% and tomato seeds treated with 25% and 75% of seeds aqueous extracts. Plumule growth inhibition was at highest level 84.85% with onion seedlings under 100% extraction concentration of wild oat seeds aqueous extracts, while lowest value was -17.19% in onion seeds under root extracts with concentration level of 75%. Highest radicle growth inhibition was 95.08% in onion seeds under the 100% extract concentration of seeds aqueous extracts, meanwhile lowest values were -5.12% in the triple combination of onion tested seeds, shoot extracts of wild oat and the concentration level of 25%. All these findings explain the importance of indicating the best bioassay plant for allelopathic studies to insure accurate and reliable results that could be manipulated for entire allelopathic researches, it is clear that wild oat plant had allelopathic effect that is concentration dependent and its root, shoot and seeds differ in their allelopathic influence (Iannucci et al., 2012, Liu et al., 2016).

3.8 Allelopathy Index Equations: After conduction the experiment, recording data of germination and seedling growth we estimated the allelopathic index (Table- 8) according to the previously proposed equations and based on seedlings dry weight.

1st Proposed Equation: - Equation (4) which depends on the difference between seedlings dry weight in control treatment and extracts treatments. The data with minus signals represent higher growth than control treatments or stimulatory effect of allelochemicals, while positive data which is above zero means allelochemicals inhibitory effects (figure-1).

2nd Proposed Equation: - This equation depends on the seedlings weight differences between control and treatments divided by general mean of total dry weight, then it will be subtracted from (1) as shown in equation (5). Control treatments will have unity data and then any data above unity will be the result of stimulation allelopathic effect and lower than unity means inhibitory effects that shows severity of allelopathic relation-ship in minus data as shown in figure (2).

3rd Proposed Equation: - This equation is the result of dividing the subtract of average dry weights of control divided by average dry weights of treatments over the subtraction from unity of average of treatments divided by general average of the both as in equation (6). Control treatments result will be zero so any data above zero will be stimulatory allelopathic effect and data below zero will represent inhibitory effects (figure-3).

4th Proposed Equation: - This equation is an attempt to proposed a percentage proportion for allelopathic effect as shown in equation (7). Where seedlings dry weight of treatments will be divided by average of control treatments then it will have subtracted from one and multiplied by 100 to indicate the allelopathic index as percentage. These results could use to compare different treatment sets (figure- 4).

5th Proposed Equation: - this equation is an attempt to represent the linear relation-ship that could manipulate allelopathic effects. In this equation there is data from the natural logarithm of each treatment and the concentration differences between treatments (equation- 8). It is obvious from (figure- 5) that the higher data means stronger allelopathic effect.

3.9 Comparison between equations: - Above equations indicate different manipulation types for instance equation (5) in this study will be the best according to the goal of indicating stimulatory or inhibitory allelopathic effects and the use of three set of averages. Equation (7) will be preferred to use in comparison of different plant species allelopathic potentiality. Both equations demonstrate stimulatory or inhibitory allelopathic effects according to plants dry weight so it will provide a reasonable solution for such studies, beside its simple and accurate bases.

4.CONCLUSION: - From these results we conclude that lettuce plants was the most suitable plant to be used as a bioassay indicator plant comparing to Tomato and Onion plants in allelopathy studies. Wild oat plant parts imposed allelopathic impact that could be classified from stronger to weaker as Shoot – seed- root and the impact was concentration dependent. From This study's analytical findings and equation results it was clear that our proposed equations (5) and (7) were better than other three proposed equations to be used in allelopathy studies as allelopathy index due to their capability to manipulate different allelopathic relationships.

Table 1. The Effect of Plant Species on Germination and Some Seedlings Growth Characteristics

Plant Species	Germination %	Inhibition %	Plumule Length (cm)	Radicle Length (cm)	Plumule Dry Weight (g)	Radicle Dry Weight (g)	Total Dry Weight (g)	Plumule Growth Inhibition %	Radicle Growth Inhibition %
lettuce	83.56 c	16.44 c	3.10 b	0.78 c	0.44 b	0.07 b	0.51 b	6.16 a	50.23 a
Onion	90.05 b	9.96 b	3.08 b	0.98 b	0.42 c	0.12 b	0.54 b	24.28 b	56.34 b
Tomato	95.73 a	4.27 a	3.81 a	2.83 a	1.24 a	0.66 a	1.91 a	25.44 b	72.89 c

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

Table 2. The Effect of Plant Part Extracts on Germination and Some Seedlings Growth Characteristics

Wild Oat Plant Part	Germination %	Inhibition %	plumule length (cm)	radicle length (cm)	plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	plumule Growth Inhibition %	Radicle Growth Inhibition %
Shoot	84.89 c	15.11 c	3.17 b	1.23 b	0.73 b	0.31 a	1.04 a	19.13 b	54.92 a
Root	95.02 a	4.98 a	4.62 a	2.37 a	0.77 a	0.29 a	1.05 a	4.63 a	58.25 a
Seed	89.42 b	10.58 b	2.20 c	0.99 c	0.60 c	0.25 a	0.85 b	32.12 c	66.29 b

Note: Means with the same symbols in one column are not significantly different from each other at

alpha = 0.01% based on multiple range test of Duncan

Table 3. The Effect of Wild Oat Extracts Concentration Levels on Germination and Some Seedlings Growth Characteristics

Extract Concentration	Germination %	Inhibition %	plumule length (cm)	radicle length (cm)	plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	plumule Growth Inhibition %	Radicle Growth Inhibition %
Control	99.85 a	0.15 a	5.40 a	3.20 a	0.90 a	0.96 a	1.86 a	0.00 a	0.00 a
25%	96.15 b	3.85 b	3.53 b	1.55 b	0.72b	0.15 b	0.87 b	12.64 b	59.97 b
50%	92.30 c	7.70 c	3.10 c	1.43 c	0.67 c	0.12 b	0.79 b	21.85 c	71.62 c
75%	84.89 d	15.11 d	2.63 d	0.86 d	0.65 c	0.10 b	0.76 bc	24.85 c	80.48 d
100%	75.70 e	24.30 e	2.00 e	0.62 e	0.55 d	0.08 b	0.64 c	33.80 d	87.03 e

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

Table 4. The Combination Effect of Bioassayed Plant Species and Wild Oat plant part extraction on Germination and Some Seedlings Growth Characteristics

Species	Extract	Germination %	Inhibition %	Plumule length (cm)	radicle length (cm)	Plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	Plumule Growth Inhibition %	Radicle Growth Inhibition %
Lettuce	Shoot	84.27 d	15.73 d	3.23 c	0.57 f	0.46 e	0.08 b	0.54 d	0.57 f	44.41 c
	root	93.07 bc	6.93 b	3.61 b	1.07 e	0.45 ef	0.07 b	0.51 d	3.40 f	52.96 b
	seed	73.33 f	26.67 f	2.45 d	0.71 f	0.41 f	0.06 b	0.47 d	14.52 e	53.33 b
Onion	Shoot	77.87 e	22.13 e	2.48 d	0.99 e	0.32 g	0.14 b	0.46 d	42.13 b	49.42 bc
	root	95.73 ab	4.27 ab	5.12 a	1.34 d	0.64 d	0.14 b	0.78 c	-16.60 g	48.73 bc
	seed	96.53 a	3.47 a	1.64 e	0.62 f	0.29 g	0.08 b	0.37 d	47.30 a	70.86 a
Tomato	Shoot	92.53 c	7.47 c	3.81 b	2.13 b	1.42 a	0.71 a	2.13 a	14.69 e	70.94 a
	root	96.27 a	3.73 a	5.12 a	4.71 a	1.21 b	0.66 a	1.87 b	27.09 d	73.05 a
	seed	98.40 a	1.60 a	2.51 d	1.65 c	1.09 c	0.62 a	1.71 b	34.54 c	74.68 a

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

Table 5. The Combination Effect of Tested Plant Species and Wild Oat extract Concentration Levels on Germination and Some Seedlings Growth Characteristics

plant species	Concentration %	Germination %	Inhibition %	plumule length (cm)	radicle length (cm)	plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	plumule Growth Inhibition %	Radicle Growth Inhibition %
Lettuce	Control	100.00 a	0.00 a	4.01 cd	1.26 e	0.48 ef	0.14 bc	0.62 de	0.00 a	0.00 a
	25%	94.22 bc	5.78 bc	3.79 d	1.00 ef	0.50 e	0.08 bc	0.58 e	-5.70 a	42.89 b
	50%	88.00 d	12.00 d	3.23 e	0.74 fg	0.43 fg	0.07 bc	0.50 e	7.73 b	48.28 b
	75%	75.11 e	24.89 e	2.70 f	0.59 gh	0.41 g	0.04 bc	0.46 e	8.97 bc	70.10 c
	100%	60.44 f	39.56 f	1.75 h	0.32 h	0.36 hi	0.01 c	0.38 e	19.82 d	89.88 d
Onion	Control	99.56 a	0.44 a	7.00 a	2.46 c	0.55 d	0.27 b	0.82 d	0.00 a	0.00 a
	25%	96.44 ab	3.56 ab	2.58 f	0.97 ef	0.47 ef	0.15 bc	0.62 de	14.93 cd	46.03 b
	50%	94.22 bc	5.78 bc	2.22 g	0.75 fg	0.39 gh	0.06 bc	0.45 e	28.93 e	76.61 c
	75%	84.89 d	15.11 d	2.02 g	0.42 h	0.34 i	0.05 bc	0.39 e	38.31 f	80.22 cd
	100%	75.11 e	24.89 e	1.58 h	0.30 h	0.33 i	0.06 bc	0.39 e	39.22 f	78.84 c
Tomato	Control	100.00 a	0.00 a	5.17 b	5.87 a	1.67 a	2.47 a	4.14 a	0.00 a	0.00 a
	25%	97.78 ab	2.22 ab	4.21 c	2.69 bc	1.19 b	0.21 bc	1.40 b	28.69 e	90.99 e
	50%	94.67 bc	5.33 bc	3.85 d	2.79 b	1.18 b	0.24 bc	1.42 b	28.88 e	89.98 de
	75%	94.67 bc	5.33 bc	3.17 e	1.56 d	1.21 b	0.21 bc	1.42 b	27.27 e	91.13 e
	100%	91.55 c	8.44 c	2.66 f	1.24 e	0.96 c	0.18 bc	1.14 c	42.35 f	92.37 e

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

Table 6. The Combination Effect of Wild Oat Part extract and extract Concentration Levels on Germination and Some Seedlings Growth Characteristics

Wild Oat Plant Part	Concentration	Germination %	Inhibition %	plumule length (cm)	radicle length (cm)	plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	plumule Growth Inhibition %	Radicle Growth Inhibition %
Shoot	Control	99.56 a	0.44 a	5.42 a	3.20 a	0.90 a	0.96 a	1.86 a	0.00 a	0.00 a
	25%	93.78 c	6.22 c	3.61 d	1.03 cd	0.77 b	0.21 b	0.98 b	5.67 ab	41.88 b

	50%	88.44 d	11.56 d	3.06 e	0.79 de	0.69 c	0.16 b	0.84 bcd	23.93 c	59.67 c
	75%	77.33 f	22.67 f	2.35 f	0.68 ef	0.76 b	0.13 b	0.89 bcd	25.67 cd	82.08 de
	100%	65.33 g	34.67 g	1.43 gh	0.45 fg	0.55 e	0.09 b	0.64 cde	40.38 e	90.99 e
Root	Control	100.00 a	0.00 a	5.39 a	3.20 a	0.90 a	0.96 a	1.86 a	0.00 a	0.00 a
	25%	99.11 ab	0.89 ab	4.83 b	2.90 a	0.77 b	0.13 b	0.90 bc	4.73 ab	63.87 c
	50%	95.56 bc	4.44 bc	4.60 b	3.05 a	0.71 c	0.13 b	0.84 bcd	9.77 b	74.19 d
	75%	94.67 c	5.33 c	4.24 c	1.54 b	0.69 c	0.10 b	0.79 bcde	8.34 b	77.21 d
	100%	85.78 de	14.22 de	4.05 c	1.18 c	0.77 b	0.11 b	0.88 bcd	0.33 a	75.97 d
Seed	Control	100.00 a	0.00 a	5.39 a	3.20 a	0.90 a	0.96 a	1.86 a	0.00 a	0.00 a
	25%	95.56 bc	4.44 bc	2.15 f	0.73 ef	0.62 d	0.10 b	0.72 cde	27.52 cd	74.15 d
	50%	92.89 c	7.11 c	1.65 g	0.45 fg	0.61 d	0.08 b	0.69 cde	31.85 d	81.01 de
	75%	82.67 e	17.33 e	1.31 h	0.36 g	0.51 e	0.07 b	0.59 ef	40.54 e	82.16 de
	100%	76.00 f	24.00 f	0.51 i	0.22 g	0.34 f	0.05 b	0.39 f	60.68 f	94.14 f

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

Table 7. The Triple Combination Effect of Tested Plant Species, Wild Oat Part extract and extract Concentration Levels on Germination and Some Seedlings Growth Characteristics

plant species	Wild Oat Plant Part	Concentration %	Germination %	Inhibition %	plumule length (cm)	radicle length (cm)	plumule dry weight (g)	radicle dry weight (g)	total dry weight (g)	plumule Growth Inhibition %	Radicle Growth Inhibition %
Lettuce	Shoot	Control	100.00 a	0.00 a	4.01 fg	1.26 e-g	0.48 j-L	0.14 b	0.62 i-m	0.00 c-e	0.00 a
		25%	92.00 b-e	8.00 b-e	4.10 fg	0.61 i-m	0.56 ij	0.08 b	0.64 h-m	-16.86 b	40.68 c
		50%	85.33 e-g	14.67 e-g	3.68 gh	0.40 k-m	0.46 k-m	0.10 b	0.57 i-n	1.92 d-f	20.04 b
		75%	77.33 h	22.67 h	2.79 jk	0.37 k-m	0.43 Lm	0.04 b	0.47 j-o	8.95 e-h	70.63 e-g
		100%	66.67 i	33.33 i	1.55 mn	0.19 m	0.37 m-o	0.01 b	0.38 j-o	8.83 e-h	90.68 h
	Root	Control	100.00 a	0.00 a	4.01 fg	1.26 f-j	0.48 j-L	0.14 b	0.62 i-m	0.00 c-e	0.00 a
		25%	100.00 a	0.00 a	4.05 fg	1.33 e-g	0.50 j-L	0.08 b	0.58 i-m	-8.39 b-d	38.99 c
		50%	96.00 a-d	4.00 a-d	3.41 h	1.23 e-g	0.43 Lm	0.05 b	0.48 j-o	6.03 e-g	63.39 d-f
		75%	92.00 b-e	8.00 b-e	3.33 hi	0.94 f-k	0.41 L-n	0.04 b	0.45 j-o	3.44 d-g	76.19 e-h
		100%	77.33 h	22.67 h	3.24 hi	0.59 i-m	0.40 L-o	0.02 b	0.42 j-o	15.93 g-i	86.21 gh
	Seed	Control	100.00 a	0.00 a	4.01 fg	1.26 e-g	0.48 j-L	0.14 b	0.62 i-m	0.00 c-e	0.00 a
		25%	90.67 c-f	9.33 c-e	3.22 h-j	1.05 f-i	0.44 Lm	0.07 b	0.51 i-o	8.17 e-h	49.01 cd
		50%	82.67 gh	17.33 gh	2.59 k	0.59 i-m	0.41 L-n	0.05 b	0.46 j-o	15.24 g-i	61.41 de
		75%	56.00 j	44.00 j	1.98 lm	0.46 j-m	0.40 L-o	0.05 b	0.45 j-o	14.51 f-i	63.49 d-f
		100%	37.33 l	62.67 l	0.47 op	0.18 m	0.31 op	0.01 b	0.32 k-o	34.70 k-n	92.76 h
Onion	Shoot	Control	98.67 ab	1.33 ab	7.07 a	2.46 d	0.55 i-K	0.27 b	0.82 f-j	0.00 c-e	0.00 a
		25%	93.33 a-d	6.67 a-d	1.85 l-n	1.03 f-j	0.50 j-L	0.31 b	0.81 f-j	8.95 e-h	-5.12 a
		50%	85.33 e-g	14.67 e-g	1.53 mn	0.65 h-m	0.28 pq	0.08 b	0.35 j-o	49.52 o	70.84 e-g
		75%	65.33 i	34.67 i	1.35 n	0.49 i-m	0.17 rs	0.03 b	0.20 m-o	68.54 p	88.86 gh
		100%	46.67 k	53.33 k	0.63 op	0.31 Lm	0.09 st	0.02 b	0.11 no	83.66 q	92.54 h
	Root	Control	100.00 a	0.00 a	6.97 a	2.46 d	0.55 i-k	0.27 b	0.82 f-j	0.00 c-e	0.00 a
		25%	100.00 a	0.00a	5.46bc	1.67 e	0.57 ij	0.10 b	0.67 h-m	-3.23 c-e	61.60 de
		50%	97.33 a-c	2.67 a-c	4.77de	1.43 e-g	0.61 i	0.08 b	0.69 h-L	-11.71 bc	70.37 e-g
		75%	97.33 a-c	2.67 a-c	4.49 ef	0.63 i-m	0.64 i	0.10 b	0.74 h-k	-17.19 b	62.79 d-f
		100%	84.00 f-h	16.00 f-h	3.94 g	0.51	0.83 h	0.14 b	0.97	-50.85 a	48.91 cd

						i-m			e-i		
		Control	100.00 a	0.00 a	6.97 a	2.46 d	0.55 i-k	0.27 b	0.82 f- j	0.00 c-e	0.00 a
		25%	96.00 a-d	4.00 a-d	0.43 op	0.23 m	0.33 n-p	0.05 b	0.38 j-o	39.07 L-o	81.59 f-h
	Seed	50%	100.00 a	0.00 a	0.36 p	0.18 m	0.28 pq	0.03 b	0.31 k-o	48.99 n	88.62 gh
		75%	92.00 b-e	8.00 b-e	0.23 p	0.14 m	0.20 qr	0.03 b	0.23 L-o	63.57 p	89.01 gh
		100%	94.67 a-d	5.33 a-d	0.19 p	0.09 m	0.08 t	0.01 b	0.10 o	84.85 q	95.08 h
		Control	100.00 a	0.00 a	5.17 b-d	5.87 b	1.67 a	2.47 a	4.14 a	0.00 c-e	0.00 a
		25%	96.00 a-d	4.00 a-d	4.89 ef	1.45 ef	1.25 bc	0.23 b	1.48 cd	24.93 i-k	90.09 gh
	Shoot	50%	94.67 a-d	5.33 a-d	3.96 g	1.32 e-g	1.33 b	0.29 b	1.61 bc	20.35 h-j	88.14 gh
		75%	89.33 d-g	10.67 d-g	2.90 i-k	1.17 e-h	1.67 a	0.31 b	1.99 b	-0.49 c-e	86.75 gh
		100%	82.67 gh	17.33 gh	2.11 L	0.86 g-L	1.19 cd	0.25 b	1.43 cd	28.64 j-m	89.74 gh
		Control	100.00 a	0.00 a	5.17 b-d	5.87 b	1.67 a	2.47 a	4.14 a	0.00 c-e	0.00 a
		25%	97.33 a-c	2.67 a-c	4.97 c-e	5.71 b	1.24 c	0.22 b	1.45 cd	25.80 i-L	91.02 h
Tomato	Root	50%	93.33 a-d	6.67 a-d	5.60 b	6.47 a	1.08 ef	0.27 b	1.35 c-e	34.98 k-n	88.80 gh
		75%	94.67 a-d	5.33 a-d	4.90 de	3.04 c	1.02 fg	0.17 b	1.19 c-g	38.77 L-o	92.66 h
		100%	96.00 a-d	4.00 a-d	4.98 c-e	2.45 d	1.07 ef	0.17 b	1.24 c-f	35.92 k-n	92.79 h
		Control	100.00 a	0.00 a	5.17 b-d	5.87 b	1.67 a	2.47 a	4.14 a	0.00 c-e	0.00 a
		25%	100.00 a	0.00 a	2.79 jk	0.91 f-k	1.08 ef	0.19 b	1.27 c- e	35.34 k-n	91.85 h
	Seed	50%	96.00 a-d	4.00 a-d	2.00 Lm	0.59 i-m	1.14 de	0.17	1.31 c-e	31.33 j-n	93.00 h
		75%	100.00a	0.00 a	1.72 L-n	0.47 j-m	0.94 g	0.14 b	1.08 d-h	43.53 no	93.98 h
		100%	96.00 a-d	4.00 a-d	0.88 o	0.39 k-m	0.63 i	0.13 b	0.76 g-k	62.49 p	94.57 h

Note: Means with the same symbols in one column are not significantly different from each other at alpha = 0.01% based on multiple range test of Duncan

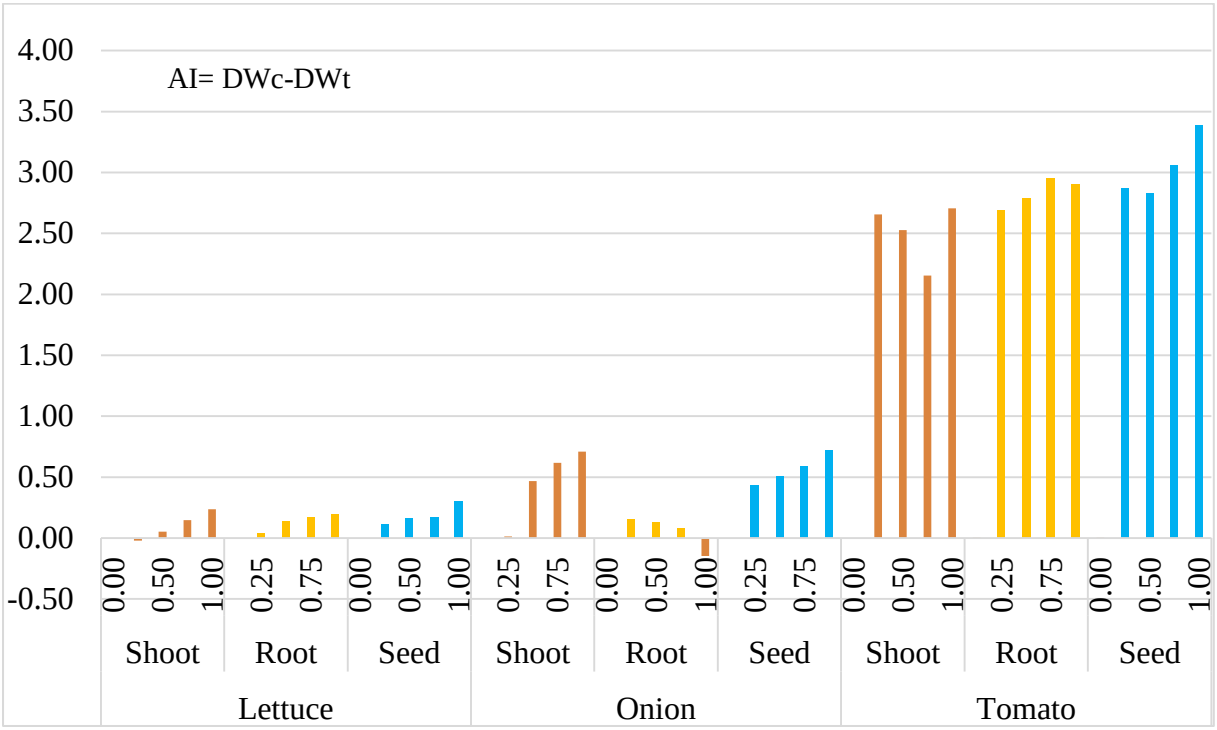
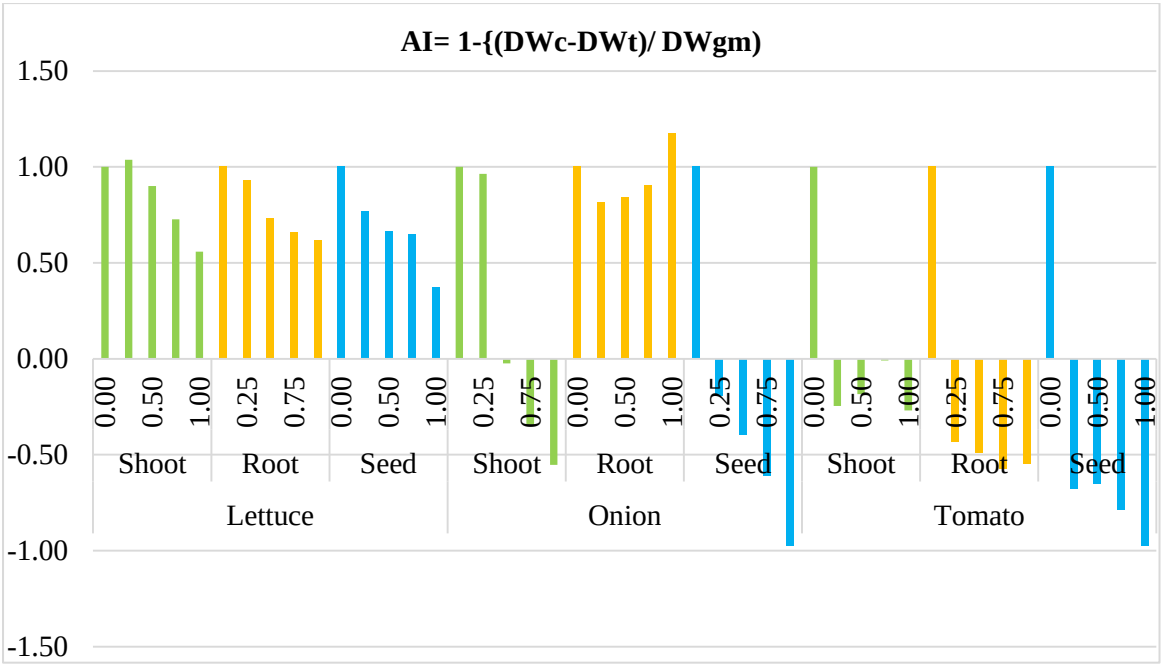
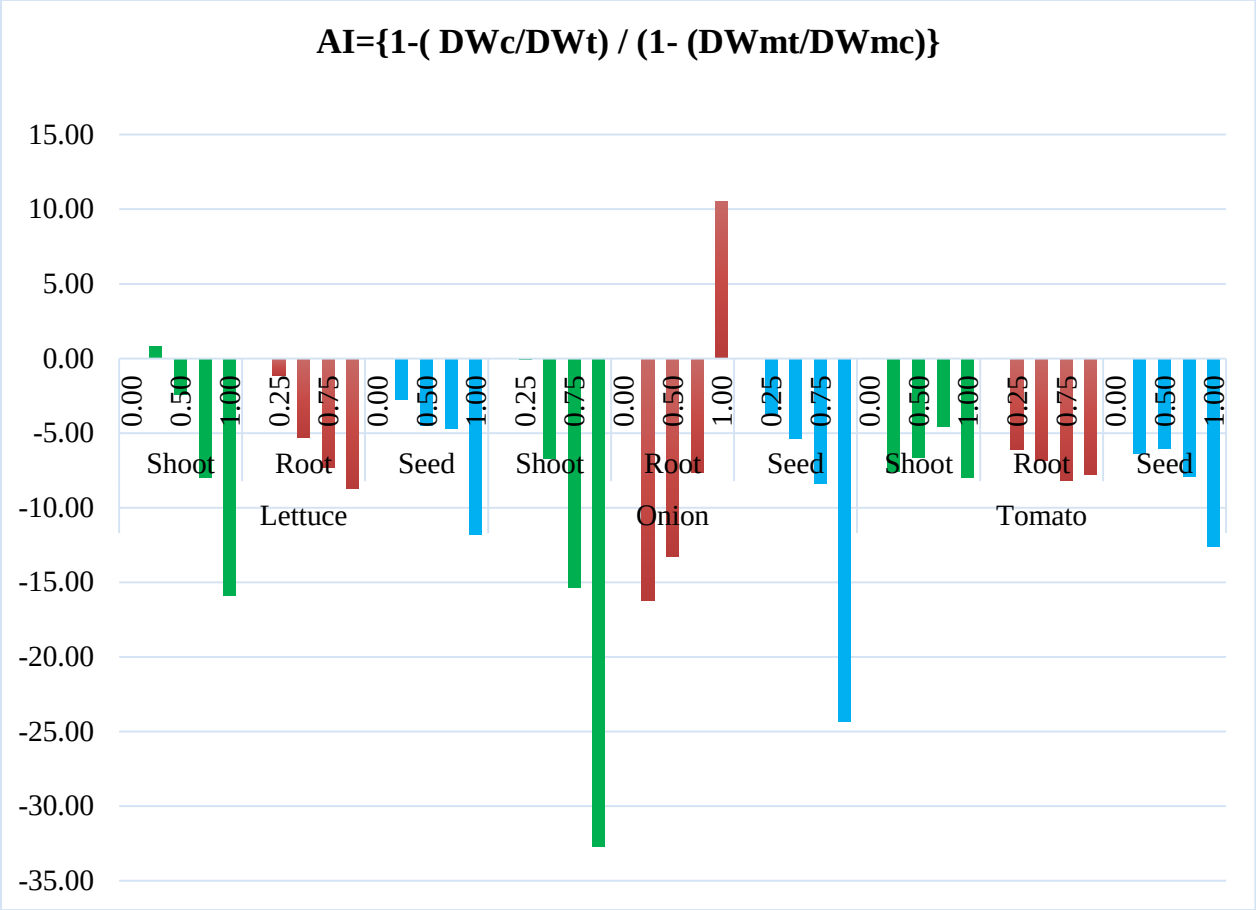


Figure 1 the Allelopathic Index according to Equation Number (4).



(Figure 2)The Allelopathic Index According to Equation(5)



(Figure 3) the Allelopathic Index According to Equation Number (6).

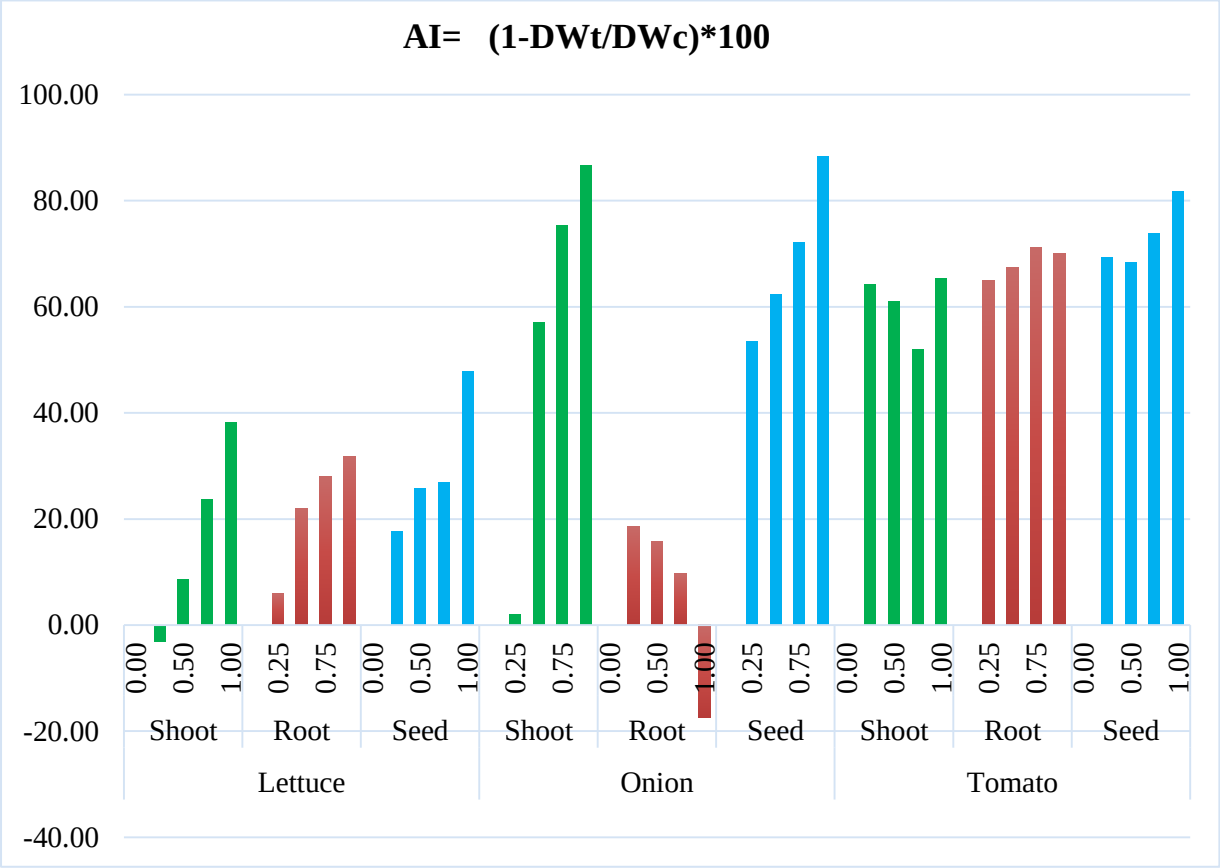


Figure 4 The Allelopathic Index According to Equation Number (7).

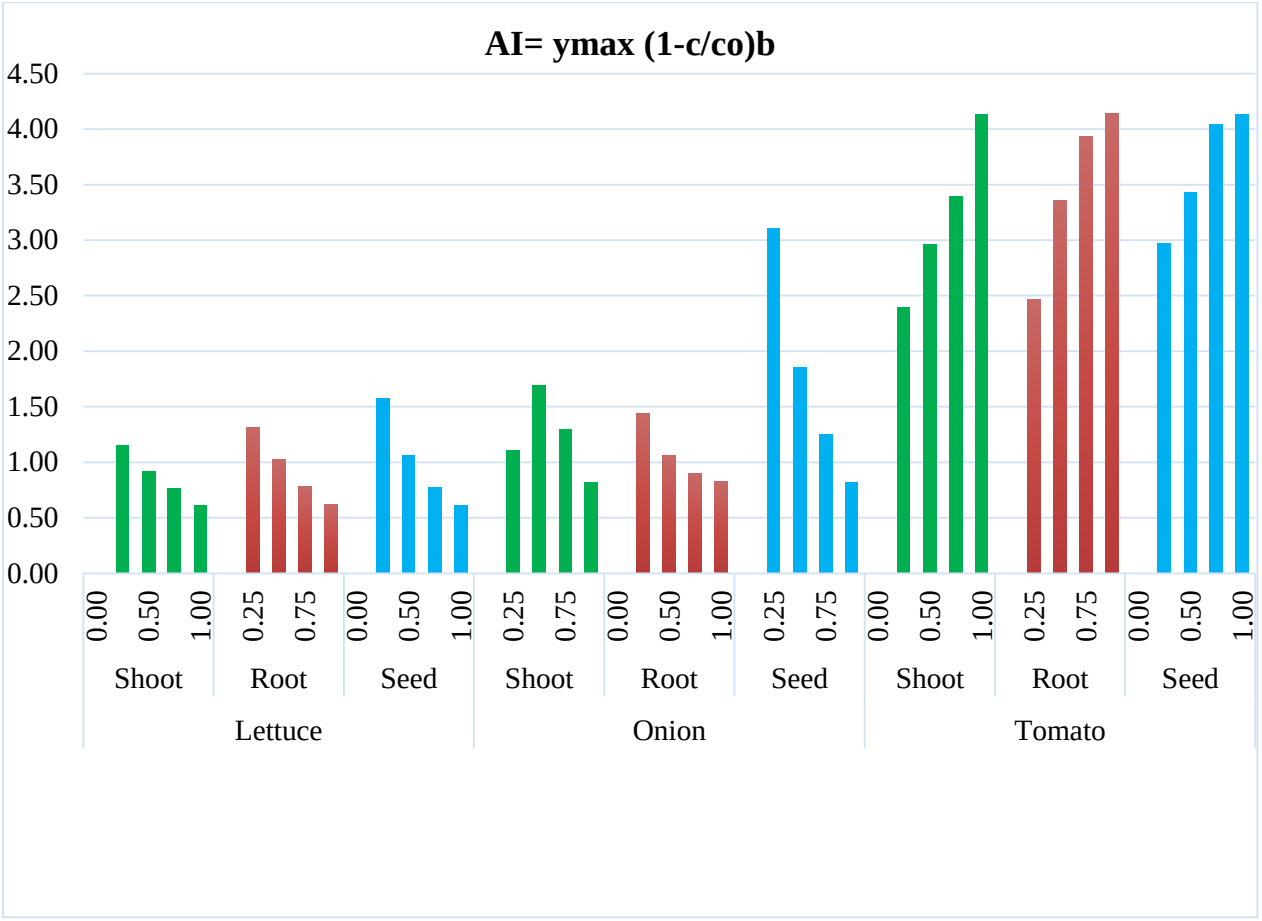


Figure 5 The Allelopathic Index According to Equation Number (8).

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