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# Humic Acid Enriched Liquid Fertilizer Development from Thermo Chemical Digestate Derived from Municipal Solid Waste

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## A B S T R A C T

Apot culture experiment was designed to develop a humic acid enriched liquid foliar nutrient formulation from thermochemical digestate obtained from food waste to increase the cumulative yield of amaranthus. Hoagland nutrient solution at strengths 0%, 25%, 50%, 75 % and 100 % combined with KOH(2 M) humic acid extract obtained from thermochemical digestate at 0% 1%, 2% and 3% strengths were applied to transplanted amaranthus once in weekly intervals. The results showed that spraying 50 % Hoagland solution enriched with 2 % humic acid extract derived from rapid thermochemical digestate of food waste was superior in terms of cumulative yield, leaf to shoot ratio, plant height, leaf width and leaf length. Even though foliar application of 75% strength of Hoagland nutrient solution with 2% strength of humic acid and 100 % Hoagland nutrient solution with 2 % humic produced a slight increase in yield and yield attributes, the increase was insignificant when compared to foliar application of 50 % Hoagland nutrient solution combined with 2 % humic acid. It is concluded that the foliar application of 50 % strength of Hoagland nutrient solution enriched with 2% humic acid extract obtained from rapid thermochemical digestate will increase the yield, leaf to shoot ratio and overall productivity of amaranthus.

## Introduction

India is one of the emerging and developing countries of Southern Asia with population growth rate of 1.4 % in 2011 (Bloom, 2011). The rapid unplanned urbanization, exploding population and change in social behaviour has led to an increase in municipal solid waste generation in India. The waste generation, increasing at an alarming rate surpasses the existing waste management systems and assimilative capacity of the environment posing serious environment hazards. The studies conducted by Sharma and Jain (2019) on the waste generation found that urban India produced 62 MT of solid waste (450 g per capita /day) out of which only 82 % was collected and 28% of which was only treated. The major portion of the waste is left untreated either dumped in open spaces or used as landfills. A review done on environmental and socio economic impact of landfills showed that the landfills can be the potential source of environmental pollution and pose serious health issues (Danthurebandara *et al.,* 2012).

The most sustainable method of waste management is the collection, segregation and recycling of the waste at the source of generation. Presently there are different ways of waste recycling like bio reprocessing or conversion into energy with methods like incineration or plasma gasification. Although the conversion of waste into energy is a rapid method, the production of toxic gases that cause serious health hazards is a major constraint (de Titto and Savino, 2019). Plasma gasification is rapid and safe method of waste management, but the initial cost of establishment and operational cost are quite high when compared to other alternatives (Byun *et al.,* 2012; Gumisiriza *et al.,* 2017). Therefore, composting of biodegradable waste is one of the economically viable and environmentally safe waste management strategies. The characterisation of MSW from the different states of India showed that 40-60 % is made of biodegradable waste with high moisture content, low calorific value but rich in nutrients (Gupta *et al.,* 2015; Suthar *et al.,* 2015; Joshi and Ahmed (2016)) that can be effectively converted to quality compost. The utilization of compost in agriculture ensures soil fertility (Ahmad *et al.,* 2016). The use of compost generated from municipal solid waste when utilized at desirable rates of application either equivalent or at a lower rate than recommended FYM rates for particular crop has shown positive effects on soil physical properties, crop growth and yield (Castillo *et al.,* 2004; Meena *et al.,* 2019).

Despite of all the positive effects, conventional composting techniques has got the disadvantage of longer time duration for process completion, leading to handling problems, open space dumbing and the production of methane a potential greenhouse gas. The thermochemical process of digestion of biodegradable waste with acid and alkali is rapid and consumes only 8 to 14 hrs for quality compost production (Sudharmaidevi *et al.,* 2017). This technique enables hygienic and rapid composting of biodegradable waste and provides a net profit of US $229 per month (US $0.101 per kg waste). Studies conducted on banana variety Nendran showed the superiority of thermo chemical digestate on the nutrient uptake and yield (Leno and Sudharmai Devi 2018). Thermo chemically produced digestate gave superior results in terms of fruit weight and number fruits in oriental pickling melon (Leno *et al.,* 2016).

The recovery of humic acid like substances from thermo chemically produced compost and the well-established concept of humic acid having positive effects when used as foliar spray (Sani 2014; Daneshvar *et al.,* 2015) and soil application in different crops (Li *et al.,* 2019). The experiment was initiated to develop a humic acid enriched fortified liquid formulation from thermochemical digestate to be utilized as foliar spray.

The foliar spray was developed for multicut variety of amaranthus, that has got enormous potential in crop diversification, revenue generation and nutritional security of small and marginal farmers (Gregory *et al.,* 2019; Yadav and Meena 2019).

## Materials and Methods

### Characterisation of waste collected and thermochemical digestate produced by rapid method

The degradable waste was collected from vegetable markets, canteens, student's hostels and agricultural farms of the College of Agriculture, Kerala Agricultural University, and Vellayani, India. The composition of the waste obtained was averaged from 10 lots of collected biodegradable waste. The physical characterisation of waste was done according to the procedure outlined by Vujić *et al.,* (2010). Chemical characterisation of parameters of rapid compost was done adhering to compost quality standards in India issued by Central pollution control board (CPCB, 2006).

### Extraction of humic acid like substances

The thermochemical process of digestion was carried out as per the patented process developed for rapid composting in the prototype machine developed (Sudharmaidevi *et al.,* 2017). The material obtained after thermochemical process was directly used for extraction using KOH 0.25 M following the process of extraction by Asing *et al.,* (2009).

### Phytotoxicity test using germination bioassay

The seed germination test was conducted to find out the toxicity of the developed liquid fertilizer as outline by (Oktiawan *et al.,* 2019) in petri plates after surface sterilization of seeds with mercuric chloride.

The seeds of amaranthus, cowpea and *Abelmosches esculentus* were used for germination bioassay. The germination percentage (Luo *et al.,* 2018), vigour index (Zhao *et al.,* 2016) and germination index (Al-Ansari *et al.,* 2016) was calculated as per the formula given below

$$\text{Germination percentage} = \frac{\text{Total number of seeds germinated X100}}{\text{Total number of seeds}}$$

Vigour index

= Germination percentage x Shoot length (mm)

Germination index (GI) = (10×n1) + (9×n2) + · · · + (1×n10) n1, n2... n10 = No. of germinated seeds on the first, second and subsequent days until the 10 th day; 10, 9... and 1 are weights given to the number of germinated seeds on the first, second and subsequent days, respectively.

### Development of liquid fertilizer

Since the humic acid purification is time consuming and laborious the extract obtained after the alkaline extraction that contains both humic and fulvicacid without humic acid separation was attempted. This method has got the additional benefit of reducing the cost involved, time required and positive effects associated with fulvic acid application (Justi *et al.,* 2019).

The extract obtained was made into serial dilutions of 0%, 1 %, 2% and 3% in Hoagland nutrient solution with at 0 %, 25%, 50 % and 75 % strengths (Waheed *et al.,* 2019). Foliar application of distilled water was considered as 0% concentration.

The experiment was laid out CRD design with 3 replications. Amaranthus was transplanted 20 days after sowing into grow bags with air dry soil belonging to Oxisols.

Various combinations of humic acid extract obtained from thermochemical digestate and Hoagland medium were applied after weekly intervals after transplantation and immediately after each harvest.

The yield attributing factors like plant height, length of leaf lamina, leaf width, leaf to stem ratio, number of branches, yield per plant, and were taken into account. The values were obtained as an average of three plants per replication. The combination that gave the highest vegetative yield was selected as foliar spray formulation in amaranthus.

### Chemical characterisation of developed liquid fertilizer

The total nitrogen was determined by Kjeldahls distillation method. Total phosphorus was estimated after digestion using Double beam UV-VIS Spectrophotometer 2201, Sytronics (Jackson, 1973). Total potassium, calcium, magnesium, boron, sulphur and micronutrients were estimated after di acid digestion with nitric and per chloric acids in GBC avanta Atomic Absorption Spectrophotometer. The water soluble carbon (Vanchikova *et al.,* 2006), humic acid (Carpenter and Smith, 1984) and fulvic acid (Baes and Bloom, 1990) were estimated.

### Statistical analyses

All data of pot culture experiment was analyzed using the Data analytical package (OP STAT-Statistical software package for agricultural research workers, Hisar, 1998) applying the techniques of analaysis of variance. The F values for treatments were compared with the table values. If the effects were significant, critical differences at the 5% significance level were calculated for effecting comparison among the means.

## Results and Discussion

The waste collected for preparation of thermochemical digestate by rapid method contained 48.9 % vegetable waste, 20 % food waste, fish waste 6.3%, garden litter 8.2%, fruit waste 7%, agricultural waste 8.6% and other inert materials 1%. The chemical and physical properties of thermochemical digestate obtained is given in Table 1. The digestate obtained was free of foul smell and lumpy in nature. The pH was slightly acidic to neutral. The mineral nutrients were within permissible limits given by FAI (2007). The mineral nutrient content of the thermo chemical digestate obtained was in accordance with the mineral nutrient value reported by Sudharmaidevi *et al.,* (2017).

Phytotoxicity test using germination bioassay showed that utilization of KOH 0.25 Mat 2 % concentration increased the vigour index of *Abelmoschus esculentus, Vigna unguiculata* and *Amaranthus L.* The shoot length (cm), germination percentage and germination Index was increased by KOH 0.25 M extract at 2 % concentration. Above 3 % concentration of the extractant the germination percent was affected and seeds failed to germinate at 10 % concentration as given in Table 2.

The results of pot experiment in amaranthus showed the plant height increased significantly with application of 2 % humic acid when compared with 0%, 1% and 3 % of humic acid. The application of Hoagland nutrient solution at concentrations 50%, 75 % and 100 % was on par. As shown in Figure (1) the interaction effect of 2% humic acid in combination with 50% Hoagland nutrient solution was on par with the plant height produced in combinations with 50 % and 75 % Hoagland nutrient solutions. The treatment combinations were not significant with respect to effect on the length of leaf lamina. Humic acid extract at 2 % concentration produced a leaf length of 10.3 cm that was comparable to leaf length (10.03 cm) produced on foliar application of 3 % humic acid as shown in Table 3. The foliar application of Hoagland nutrient solution at50 % concentration increased the leaf lamina length compared to 0% and 25 % Hoagland nutrient solution. The increase in leaf lamina length on application of 75 % and 100 % Hoagland nutrient solution was not significantly different from Hoagland nutrient media spraying at 50 % strength. The treatment interaction effects were not significant with respect to the leaf width of amaranthus (Table 4). The foliar application of humic acid at 2 % concentration increased the leaf width (9.01cm) that was comparable with foliar application of 3% humic acid (10.22 cm). The Hoagland treatments with 50%, 75 % and 100 % produced comparable increase in leaf width of amaranthus when compared to 0 % and 25 % foliar spray of Hoagland nutrient solutions enriched with 2% humic acid extract.

Interaction effect of treatments were significant with respect to the number of branches produced, leaf to shoot ratio and cumulative yield per plant.

The recorded number of branches were highly significant at $p \leq 0.05$ (12.4 and 12.5) with treatment combination of 2% humic acid extract and Hoagland nutrient solutions of 50 % and 75 %. The foliar application of 2 % humic acid increased the number of branches compared to 3% humic acid extract application as in Table 5. Hoagland nutrient solutions at 50 %, 75 %, 100% increased the number of branches compared to spraying with distilled water or Hoagland nutrient solution at 25 %. The leaf to shoot ratio was low in treatment combinations that received 0%, 1 % and 3 % humic acid foliar spray compared to 2 % humic acid extract spraying in combination at 50 %, 75 % and 100 % Hoagland nutrient solution as in Table 6.

The cumulative yield recorded showed that there is a two-fold increase in treatments with foliar spraying of 2 % humic acid extract was combined with Hoagland nutrient solution at 50 % concentration.

The yield obtained on application of 75 % and 100 % Hoagland nutrient with 2 % humic acid extract was significantly higher than other treatment combinations as given in Table7.

A liquid fertilizer formulation was developed for amaranthus was characterised for the chemical properties (Table 7). The formulation has a shelf life of 180 days and could be sprayed in field with 10 times dilution to increase the yield of amaranthus.

The productivity of amaranthus increases on the application of fertilizers (Preetha *et al.,* 2006). Among the different methods of fertilizer application foliar application of nutrients aids better nutrient absorption and productivity in most of the crops (Yildirim *et al.,* 2007).

The foliar application of biostimulants derived from compost samples combined with soil application of fertilizers increased the yield and nutritive value of amaranthus (Ngoroyemoto *et al.,* 2019). The foliar application of humic acid extracted from the thermochemical digestate using KOH 2M extractant acts as a biostimulant in amaranthus and aided in better nutrient absorption. The increase in crop height and enhanced absorption of nutrients in canola was reported on application of humic acid and biostimulants (Sani., 2014*).* Similar results were obtained in amaranthus, wherein the height of the plant increased due to application of humic acid. The higher cumulative yield of amaranthus was recorded in treatments that received 2% humic acid in 50 % strength of Hoagland nutrient solution due to added benefit of NPK, secondary and micro nutrient in available forms on application of Hoagland nutrient solution. The application of soluble nutrient forms resulted in better absorption and higher vegetative growth in amaranthus.

Moreover, application of humic acids increases the permeability of the plant membranes and intensifies the enzyme systems of plants and aids in better nutrient absorption (Khaled and Fawy, 2011). Humic acid application accelerates cell division and resulted in higher vegetative growth and increased the number of branches in amaranthus (Fathima and Denesh, 2013).

**Table.1** Physical and chemical properties of thermochemical digestate

| SL No. | Physical and chemical properties | Values |
|---|---|---|
| **1** | Colour | Dark brown |
| **2** | Odour | Odourless |
| **3** | pH | 6.7-7.3 |
| **4** | EC ds $m^{-1}$ | 1.71± 0.14 |
| **5** | Texture | Lumps |
| **6** | Moisture (%) | 18.3±1.8 |
| **7** | TOC (%) | 25.83 ± 2.8 |
| **8** | N(%) | 1.48 ± 0.06 |
| **9** | P(%) | 0.51 ± 0.17 |
| **10** | K (%) | 0.81 ± 0.28 |
| **11** | Ca (mg $kg^{-1}$) | 273 ± 14 |
| **12** | Mg (mg $kg^{-1}$) | 287 ± 25 |
| **13** | S (mg $kg^{-1}$) | 245 ± 42 |
| **14** | Mn (mg $kg^{-1}$) | 8.6 ± 2.6 |
| **15** | Zn (mg $kg^{-1}$) | 9.1 ± 0.19 |
| **16** | Cu (mg $kg^{-1}$) | 1.8 ± 0.15 |
| **17** | B (mg $kg^{-1}$) | 0.21 ± 0.06 |

**Table.2** Phytotoxicity study using germination bioassay

| Treatment | Vigour index | Shoot length(cm) | Germination (%) | Germination index |
|---|---|---|---|---|
| ***Abelmoschus esculentus*** | | | | |
| **KOH 2 M 1%** | $227.6^{b}$ | $3.2^{b}$ | $71.1^{b}$ | $80.0^{b}$ |
| **KOH 2M 2%** | $410.7^{a}$ | $4.3^{a}$ | $95.5^{a}$ | $107.5^{a}$ |
| **KOH 2 M 3%** | $64.3^{c}$ | $2.8^{b}$ | $68.3^{b}$ | $54.8^{c}$ |
| **KOH 2M 6 %** | $52.8^{c}$ | $1.4^{c}$ | $48.5^{c}$ | $43.6^{c}$ |
| **KOH 2M 10 %** | 0.0 | 0.0 | 0.0 | 0.0 |
| **CD(0,0.05)** | 58.4 | 0.96 | 9.1 | 15.7 |
| ***Vigna unguiculata*** | | | | |
| **KOH 2 M 1%** | $241.9^{b}$ | $3.3^{b}$ | $70.8^{b}$ | $89.2^{a}$ |
| **KOH 2M 2%** | $391.9^{a}$ | $4.2^{a}$ | $98.2^{a}$ | $104.8^{a}$ |
| **KOH 2 M 3%** | $59.9^{c}$ | $2.6^{b}$ | $54.8^{b}$ | $59.6^{b}$ |
| **KOH 2M 6 %** | $43.6^{c}$ | $2.0^{c}$ | $50.2^{b}$ | $52.8^{b}$ |
| **KOH 2M 10 %** | 0.0 | 0.0 | 0.0 | 0.0 |
| **CD(0,0.05)** | 43.3 | 0.88 | 19.9 | 16.3 |
| ***Amaranthus L*** | | | | |
| **KOH 2 M 1%** | $298.9^{b}$ | $3.5^{b}$ | $73.3^{b}$ | $82.5^{b}$ |
| **KOH 2M 2%** | $418.8^{a}$ | $4.8^{a}$ | $93.3^{a}$ | $105.0^{a}$ |
| **KOH 2 M 3%** | $112.3^{c}$ | $2.3^{c}$ | $72.1^{b}$ | $41.3^{c}$ |
| **KOH 2M 6 %** | $97.4^{c}$ | $1.2^{d}$ | $36.5^{c}$ | $38.6^{c}$ |
| **KOH 2M 10 %** | $82.8^{c}$ | 0.0 | 0.0 | 0.0 |
| **CD(0,0.05)** | 30.9 | 0.74 | 14.8 | 12.8 |

Values with the same superscript are not significant, $p \leq 0.05$ CD is the Critical difference

**Table.3** The effect of treatments on length of leaf lamina (cm)

| Leaf lamina (cm) | HG 0 % | HG 1 % | HG 2 % | HG 3 % | HG 4 % | Mean |
|---|---|---|---|---|---|---|
| HA 0 % | 8.5 | 9.0 | 9.3 | 9.5 | 9.5 | $9.2^{b}$ |
| HA 1 % | 8.5 | 8.9 | 9.1 | 9.0 | 9.3 | $9.0^{b}$ |
| HA 2 % | 9.2 | 9.7 | 10.6 | 11.0 | 11.1 | $10.3^{a}$ |
| HA 3 % | 9.5 | 9.4 | 10.1 | 10.3 | 10.7 | $10.0^{a}$ |
| Mean | $8.9^{b}$ | $9.2^{b}$ | $9.8^{a}$ | $9.9^{a}$ | $10.1^{a}$ | 9.62 |

HA is humic acid; HG is Hoagland nutrient solution ; values with the same superscript are not significant
$(p\leq 0.05)_{HG}$0.54
$(p\leq 0.05)_{HA}$ 0.48

**Table.4** The effect of treatments on leaf width (cm)

| Leaf width (cm) | HG 0% | HG 25% | HG 50% | HG 75% | HG 100% | Mean HA |
|---|---|---|---|---|---|---|
| HA 0% | 8.41 | 8.44 | 8.66 | 8.70 | 8.73 | $8.59^{c}$ |
| HA 1% | 9.04 | 8.72 | 8.74 | 8.77 | 8.96 | $8.85^{c}$ |
| HA 2 % | 8.88 | 8.91 | 8.93 | 8.85 | 9.48 | $9.01^{b}$ |
| HA 3% | 9.53 | 10.33 | 10.30 | 10.51 | 10.44 | $10.22^{a}$ |
| Mean HG | $8.96^{b}$ | $9.10^{b}$ | $9.16^{a}$ | $9.21^{a}$ | $9.40^{a}$ | 9.16 |

HA is humic acid; HG is Hoagland nutrient solution ; values with the same superscript are not significant
$(p\leq 0.05)_{HG}$ 0.28$(p\leq 0.05)_{HA}$ 0.24

**Table.5** The effect of treatments on number of branches

| Number of branches | HG 0% | HG 25% | HG 50% | HG 75% | HG 100% | Mean HA |
|---|---|---|---|---|---|---|
| HA 0% | $9.09^{d}$ | $9.19^{d}$ | $9.22^{d}$ | $9.26^{d}$ | $9.28^{d}$ | $9.21^{d}$ |
| HA 1% | $9.12^{d}$ | $9.39^{d}$ | $10.53^{b}$ | $10.57^{c}$ | $10.58^{b}$ | $10.04^{c}$ |
| HA 2 % | $10.29^{c}$ | $11.05^{b}$ | $12.44^{a}$ | $12.47^{a}$ | $11.15^{b}$ | $11.48^{a}$ |
| HA 3% | $10.27^{c}$ | $10.34^{c}$ | $10.43^{c}$ | $10.22^{c}$ | $11.21^{b}$ | $10.49^{b}$ |
| Mean HG | $9.69^{b}$ | $9.99^{b}$ | $10.65^{a}$ | $10.63^{a}$ | $10.56^{a}$ | 10.30 |

HA is humic acid; HG is Hoagland nutrient solution ; values with the same superscript are not significant
$(p\leq 0.05)_{HG}$ 0.38; $(p\leq 0.05)_{HA}$ 0.34;|$(p\leq 0.05)_{HGxHA}$0.77

**Table.6** The effect of treatments on leaf to shoot ratio

| Leaf to shoot ratio | HG 0% | HG 25% | HG 50% | HG 75% | HG 100% | Mean HA |
|---|---|---|---|---|---|---|
| HA 0% | $0.41^{d}$ | $0.47^{c}$ | $0.49^{c}$ | $0.48^{c}$ | $0.48^{c}$ | $0.47^{c}$ |
| HA 1% | $0.51^{c}$ | $0.52^{c}$ | $0.53^{c}$ | $0.53^{c}$ | $0.54^{c}$ | $0.53^{b}$ |
| HA 2 % | $0.53^{c}$ | 0.56 | $0.84^{a}$ | $0.86^{a}$ | $0.84^{a}$ | $0.73^{a}$ |
| HA 3% | $0.51^{c}$ | $0.60^{b}$ | $0.59^{b}$ | $0.59^{b}$ | 0.58 | $0.57^{b}$ |
| Mean HG | $0.49^{b}$ | $0.54^{b}$ | $0.61^{a}$ | $0.61^{a}$ | $0.61^{a}$ | 0.57 |

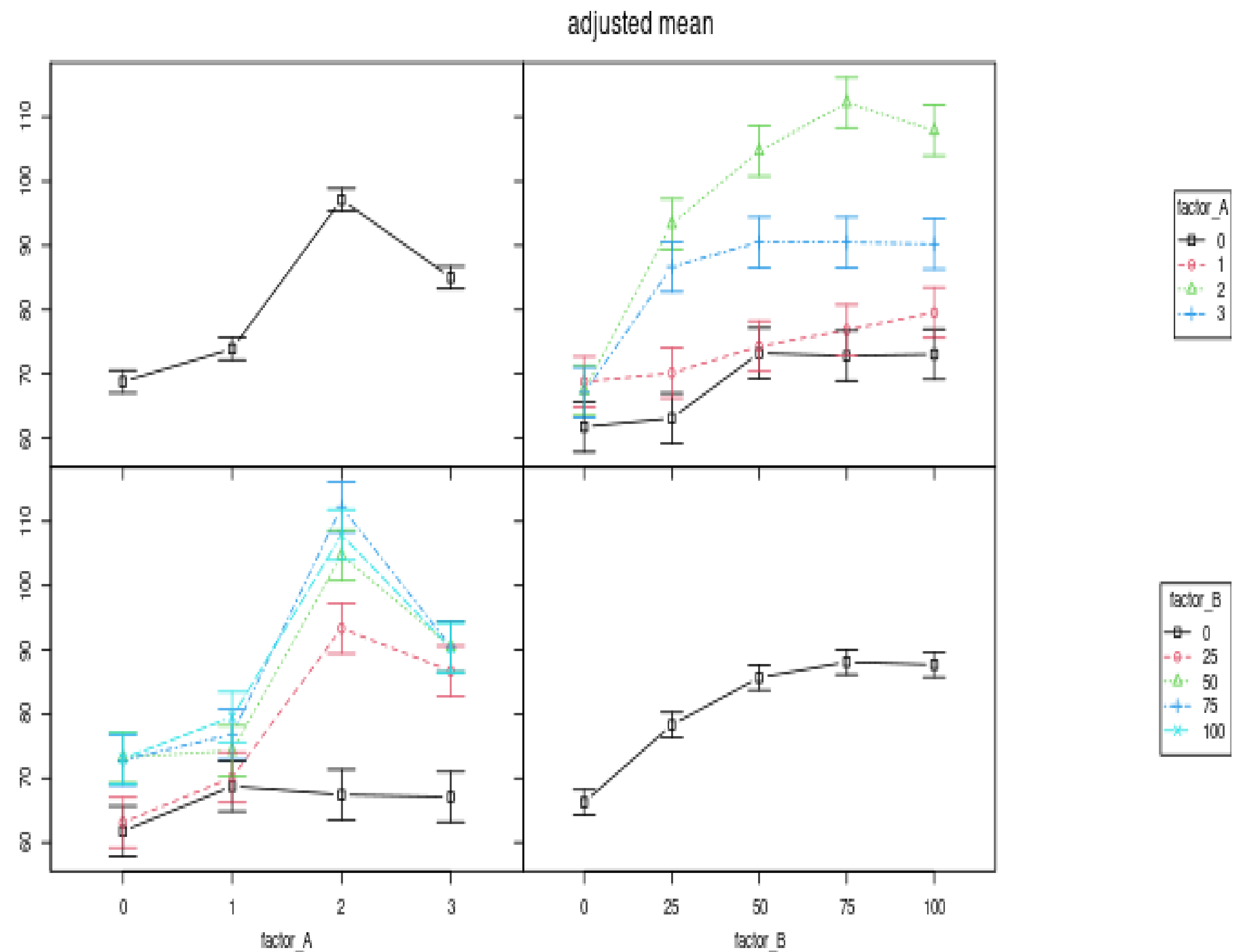
HA is humic acid; HG is Hoagland nutrient solution ; values with the same superscript are not significant
$(p\leq 0.05)_{HG}$ 0.047; $(p\leq 0.05)_{HA}$0.042;|$(p\leq 0.05)_{HGxHA}$0.093

**Table.7** Treatment effects on the cumulative yield of amaranthus

| Cumulative yield (g plant$^{-1}$) | HG 0% | HG 25% | HG 50% | HG 75% | HG 100% | Mean HA |
|---|---|---|---|---|---|---|
| **HA 0%** | 145.90$^{d}$ | 146.63$^{d}$ | 162.23$^{d}$ | 164.50$^{d}$ | 167.90$^{d}$ | 157.43$^{c}$ |
| **HA 1%** | 236.67$^{c}$ | 236.63$^{c}$ | 262.53$^{b}$ | 264.03$^{b}$ | 271.47$^{b}$ | 254.27$^{b}$ |
| **HA 2 %** | 248.10$^{b}$ | 274.23$^{b}$ | 377.26$^{a}$ | 378.57$^{a}$ | 378.40$^{a}$ | 331.31$^{a}$ |
| **HA 3%** | 240.67$^{c}$ | 241.80$^{c}$ | 243.50$^{b}$ | 244.50$^{b}$ | 240.83$^{c}$ | 242.26$^{b}$ |
| **Mean HG** | 217.83$^{b}$ | 224.83$^{b}$ | 261.38$^{a}$ | 262.90$^{a}$ | 264.65$^{a}$ | 246.31 |

HA is humic acid; HG is Hoagland nutrient solution ; values with the same superscript are not significant ($p \leq 0.05$) $_{HG}$15.4; ($p \leq 0.05$) $_{HA}$13.8;|($p \leq 0.05$)$_{HGxHA}$30.8

**Fig.1** The effect of treatments on plant height




Factor A is Humic acid extract
Factor B is Hoagland nutrient solution

**Table.8** Chemical characterisation of Liquid fertilizer formulation

| Sl.No. | Parameter | Units | Contents |
|---|---|---|---|
| 1. | pH | | 6.8 -7.2 |
| 2. | EC | $dSm^{-1}$ | 1.93 ± 0.12 |
| 3. | N | % | 1.24 ± 0.14 |
| 4. | P | % | 0.42 ±0.08 |
| 5. | K | % | 1.76 ± 0.53 |
| 6. | Ca | % | 1.9 ± 0.09 |
| 7. | Mg | % | 0.46 ± 0.22 |
| 8. | S | % | 0.21 ±0.02 |
| 9. | B | mg $kg^{-1}$ | 0.29 ± 0.02 |
| 10. | Fe | mg $kg^{-1}$ | 308 ± 0.42 |
| 11. | Cu | mg $kg^{-1}$ | 16.02 ± 0.57 |
| 12. | Zn | mg $kg^{-1}$ | 150.22 ± 0.26 |
| 13. | Mn | mg $kg^{-1}$ | 70.41 ± 0.17 |
| 14. | Water soluble carbon | mg $kg^{-1}$ | 3.32 ± 0.82 |
| 15. | $C_{HA}$ | g $l^{-1}$ | 3.9 ± 0.69 |
| 16. | $C_{FA}$ | g $l^{-1}$ | 12.2 ± 0.73 |

The biostimulant action of humic acid along with availability of nitrogen, an integral part of chlorophyll and micronutrients present in Hoagland solution resulted in increased leaf width and leaf length of amaranthus this finding is in agreement with findings of Waheed *et al.,* (2019). The increase in leaf width and leaf length increased the leaf area, this in turn increases the photosynthetic area and photosynthetic efficiency that has resulted in higher leaf to shoot ratio and yield in treatments that receive 2% humic acid in 50 %, Hoagland nutrient solution.

The low leaf to shoot ratio, lesser branches, leaf width, leaf length and plant height in treatments receiving lower concentration of humic acid and Hoagland nutrient solution may be due to the insufficient supply of nutrients. The phytotoxicity at concentration above 6% may be due to the increase in total nitrogen or the presence of higher total organic carbon even though the tolerance level changes depending upon the seeds used for germination testing.

The application of foliar spray of humic acid can effectively increase the plant height and leaf to shoot ratio of amaranthus. The leaf length, leaf width and number of branches were increased due to application of 2 % humic acid extract in combination with 50 % Hoagland nutrient solution.

The foliar application of 2 % humic acid extract in combination with 50 % Hoagland nutrient solution can be utilized as foliar spray to increase the yield of amaranthus. The developed liquid fertilizer has nutrients within the permissible limit and shelf life of more than 180 days and can be used at 20 % dilution.

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