Effects of simulated acid rain on the morphology, phenology and yield of Okra (Abelmoschus esculentus (L.) Moench)

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Research Article

Effects of simulated acid rain on the morphology, phenology and yield of Okra (*Abelmoschus esculentus* (L). Moench)

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Abstract: This study aims to investigate the effects of simulated acid rain (SAR) on the morphology, phenology and yield of okra (*Abelmoschus esculentus* (L.) Moench) to identify the pH range in which okra is resistant to acid rain and to determine the order of SAR-induced severity in okra in terms of the parameters studied. Okra seeds (NH-34 variety) were grown in a screen house. Two weeks after planting, SAR was applied to the okra seedlings at pH 1.0, 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 (control), for a period of 94 days after planting following the method of Lal and Singh (2012). Digital photographs of the morphological/phenological defects were taken including the recording of flowering and fruiting time as well as dry biomass determination. SAR-induced morphological defects in okra include chlorosis, dehydration, wilting, early leaf senescence, pathogen infection and death. Phenological observations revealed that all the treatments studied (including the control) except pH 4.0, had delayed first flower emergence on the 9th week. The result showed that okra is resistant to SAR from pH 5.0 to neutral (in terms of morphology, phenology and yield) and exhibits the following SAR-induced order of severity: Morphology >Yield > Phenology. This is the first research on the effects of SAR on morphology, phenology and yield of okra from seed to maturity. Okra is an economically-important Tropical and sub-Tropical vegetable; therefore, studying its acidic tolerance or vulnerability will help evaluate its food status in the face of anthropogenic-induced acidic deposition.

Keywords: Acid rain; pH; SAR; Okra; Phenology; Morphology; Yield.

INTRODUCTION

Since the beginning of civilization, human beings have been exploiting natural resources to their benefit in order to improve their standard of living. Most human activities are energy-driven and often derived from the combustion of fossil fuels such as coal, oil and natural gases. The rapid development brought about by the utilization of these resources, has also led to the pollution of our environment by the release of harmful byproducts as fossils are combusted[1]. The burning of fossil fuels consequently increases the concentrations of gaseous and particulate pollutants in the atmosphere leading to air pollution[2]. Acid rain is a broad term that describes several ways through which acid falls out from the atmosphere. It includes acidic rain, fog, hail and snow; therefore, 'acid deposition' is a preferred term to describe the process[1]. The average pH of non-polluted rain, mostly in forested regions, is 5.6 (due to the presence of carbonic acid produced from the dissolution of CO_2 in water) while the pH of acidic depositions is expected to be lower. The most prominent components of acid rain are sulphuric acid and nitric acid derived largely from the combustion of fossil fuels[3]. Acid rain deposition has considerable effects on both the biotic and abiotic components of an ecosystem by killing aquatic life, trees, crops and other vegetation; damaging buildings and monuments; corroding copper and lead piping; reducing soil fertility and can cause metals to leach into underground drinking water sources[4]. Atmospheric acid deposition was identified as a major environmental problem in the following countries: Canada, England, Scotland, Sweden, Norway, Denmark, West Germany, The Netherland, Austria, Switzerland, Russia, Poland, Czechoslovakia, Southwest China and Japan[1,5]. Vehicular and industrial emissions were identified as the main sources of the acidic depositions[1].

Okra (*Abelmoschus esculentus*) is an economically-important vegetable crop grown in Tropical and sub-Tropical parts of the world. This crop is suitable for cultivation as a garden crop as well as on large commercial farms[6]. It is grown commercially in India, Turkey, Iran, Western Africa, Yugoslavia, Bangladesh, Afghanistan, Pakistan, Burma, Japan, Malaysia, Brazil, Ghana, Ethiopia, Cyprus and the Southern United States[6]. It contains no fat or cholesterol but rich in soluble and insoluble fibres, vitamins and essential minerals e.g. potassium, magnesium and iron. Okra is said to be very useful against genito-urinary disorders, spermatorrhoea and chronic dysentery[7]. Its medicinal value has also been reported in curing ulcers and relief hemorrhoids[8]. Extracts from the seeds of the okra is an alternative source for edible oil. The greenish yellow edible oil has a pleasant taste and odour, and is high in unsaturated fats such as oleic acid and linoleic acid[9]. Okra provides an important source of vitamins, calcium, potassium and other mineral matters which are often lacking in the diet in developing countries[9]. The crop is famous for its wide range of edible parts and known by many local names in different parts of the world[10]. The world's Okra production was estimated at 4.8 million tons in 2007 with India leading the production followed by Nigeria, Pakistan, Ghana, Egypt and Iraq[11]. It is an excellent source of iodine; useful for the control of goiter; recommended for those suffering from heart weakness[12,13]. Saifullah and Rabbani[14] reported that okra is a nutritious vegetable containing 86.1 % water, 2.2 % protein, 0.2 % fat, 9.7 % carbohydrate, 1.0 % fibre and 0.8 % ash.

Okra is an annual plant, mainly propagated by seeds and has duration of 90-100 days to attain maturity[6]. Its stem is robust, erect, and variable in branching and varying from 0.5 to 4.0 metres in height. The okra fruit contains numerous oval, smooth, striated and dark green to dark brown seeds. The pH range of rain between 6.0 and 6.8 is ideally-suited for okra's growth and development[6]. Prior to cultivation, the seeds are soaked overnight and planted at a depth of 1-2cm with spacing of 60cm x 30cm. Germination occurs between six days (soaked seeds) and three weeks. Leaves are alternate and usually palmately five-lobed while the flower is axillary and solitary. The plant usually bears its first flower one to two months after sowing[6]. The okra flowers are 4-8 cm in diameter, with five white to yellow petals, often with a red or purple spot at the base of each petal and the flower withers within one day[6]. A flower bud takes about 22-26 days from initiation to full bloom. The pollen may come in contact with the stigmas through a lengthening of the staminal column or through insect foraging[15]. Thus, the flowers of okra are self-fertile.

Acid rain exposure to plants results in characteristic foliar injury symptoms, modified leaf anatomy, structural changes in the photosynthetic pigment apparatus and a decrease in chlorophyll a and b contents[16,17]. Simulated acid rain (SAR) exposure alters the ability of plants to take in CO_2 for photosynthesis that consequently inhibits the production of reducing sugars such as glucose[18]. Singh and Agrawal[19] reported that the shoot and root lengths, leaf areas, and total biomass or yield of two varieties of wheat declined significantly at or below pH 4.0 and concluded that simulated acid rain had a significantly negative effect on wheat. A more recent report by Madiha *et al.*[20] revealed that simulated acid rain also caused reduction in plant growth and yield of field corn, green pepper and tomato. Compared with other crops, vegetables are expected to be more sensitive to acid rain[21]. Based on the field investigations and experiment results, the effects of acid rain on vegetables include poor seed germination and seedling growth; leaf injury[21], interference with normal metabolism[22,23], growth and yield[24] as well as nutritional quality. There exist only one previous research on the effects of SAR on okra which was conducted by Shaukat and Khan[25] who investigated the growth and physiological responses of okra to SAR (at pH 4.0) and root-knot nematode, *Meloidogyne incognita*. Single and combined treatments of okra with SAR and *M. incognita* caused white-to-tan spots on the leave surfaces; significant suppression of pigment synthesis; reduction in shoot and root weights, and yield; reduction in non-reducing sugars but an increase in soluble phenols.

This study investigated for the first time, the effects of SAR on the morphology, phenology and yield of okra at pH 1.0, 2.0. 3.0. 4.0, 5.0, 6.0 and 7.0 (control) from seed to maturity. The objectives of this research are: To investigate the pH range in which okra is resistant to acid rain; to determine the order of SAR-induced severity in okra in terms of morphology, phenology (flowering and fruiting time and development) and yield. This research is expected to provide information on the degree of vulnerability or resistance of okra as the acidity of atmospheric rain gradually increases due to anthropogenic sources, and serve as a study template for other tropical and sub-tropical vegetables that have the potential to be resistant to acid rain.

MATERIALS AND METHOD

Study site: The site used for this research is situated beside the Academic building, located behind the School of Sciences (SOS) building at Obanla campus, the Federal University of Technology, Akure (FUTA), Ondo state, Nigeria. A screen house was required for this research and its main function was to prevent grasshoppers and other voracious phytophagous arthropods from consuming the okra plant as it grows to maturity.

Materials used in planting: Okra seeds of variety NH-34 produced by NIHORT (National Horticultural Research Institute) in Nigeria, and horticultural pots were obtained from the Agricultural Developmental

Project (ADP), Akure, Ondo State, Nigeria. Loamy soil was also collected at the back of the Security building behind SOS, FUTA.

Materials used for acid rain formulation: Electronic weighing balance (JA3003), four beakers, pH meter (Model PHS-25), funnel, two bowls, seven kegs (20 litres each), water, wooden stirrer, cup with handle, standard buffers 4.0 and 7.0, rubber gloves, distilled water (300ml), paper tape, tissue paper, Hydrogen Tetraoxosulphate VI acid (H_2SO_4) and Sodium Hydroxide (NaOH) pellets.

Preparation of simulated acid rain: Firstly, the standard buffers 4.0 and 7.0 were dissolved in 100ml of distilled water separately in a beaker, then poured into a container and temporarily preserved in a refrigerator. A pH meter was later used to confirm the pH values of the buffers. The purpose of the buffer solutions is to standardize the pH meter in order to reduce errors. The kegs (20 litres each) were filled with water and emptied into a bowl. The pH meter was switched on and standardized by dipping the electrode into the prepared buffer solutions 4.0 and 7.0. Little quantity of concentrated H_2SO_4 was poured repeated into the bowl of water and stirred thoroughly with a wooden stirrer until the required pH was obtained. Tissue paper was used to clean the tip of the electrode of the pH meter before inserting it into the buffer solutions to re-standardize the pH meter. The same procedure was applied for the preparation of other pH values until the six acidic values were obtained (pH 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0). As for the preparation of the control (pH 7.0), 1g of NaOH was weighed and dissolved into 100ml of distilled water. Few drops of the NaOH solution were then added to a bowl of water and stirred thoroughly until the required pH (7.0) value was obtained. Rubber gloves were worn for protection against the concentrated acid and base. After preparing each pH value, the solution obtained was poured back into the respective kegs with the aid of a cup and funnel, and a paper tape was then used to label the kegs according to the pH values of the solution contained within.

Experimental procedure: Twenty-eight horticultural pots representing 7 treatments (i.e. pH 1.0, 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0) with 4 replicates each were arranged according to their respective pH values. pH 1.0 to 6.0 represented the treatments while pH 7.0 stood as the control. The okra seeds were soaked for 16 hours before planting in order to soften the seed coat and hasten germination. About ¾ of the pots were filled with loamy soil before planting the seeds. Four viable seeds were planted in each pot and watered daily; germination was achieved after 5 days of planting. Thinning was done after 14 days of planting, leaving one individual plant per pot. Weeding was also consistent to eliminate potential competitors. A hand-held sprayer was used to apply the simulated acid sporadically to mimic natural rain. After 2 weeks of planting, spraying of 30ml acid of different pH values once in a week was carried out following the methods of Lal and Singh[26]. The experiment was terminated approximately 12 weeks (80 days) after commencement of treatment (i.e. 94 days after planting).

Morphological studies: The experimental set-up was observed every 2 days to record significant changes in the morphological features of the okra plant. Relevant literature showed that acid rain could induce morphological defects such as chlorosis, necrosis, dehydration, early leaf senescence, discolouration, wilting, pathogen infection and death in plants. Pictorial images of the morphological defects were taken with a digital camera to record the effects of SAR on okra.

Phenological studies: Similar to the morphological studies, observations on phenological studies were also made every 2 days. The first flower and fruit emergence time was recorded and the total number of flowers and fruits of individual replicates were noted. In addition, pictorial images of the phenological defects due to SAR such as poorly-developed fruits and flowers were taken with a digital camera.

Determination of dry biomass (yield): The okra plants were harvested and the shoots were separated from the roots at the soil line region. The roots were rinsed with water to remove the soil particles attached to them. The roots and shoots (including the fruits and flowers) were kept in separate brown envelopes and dried in a cabinet (Splintex TBSS190182) at 60˚C for 4 days. Before drying the okra plants, the average weight of the envelopes was determined. After drying, the envelopes containing the roots and shoots were weighed separately and then recorded. The actual weight of the roots and shoots was obtained by deducting the mean weight of the empty envelopes from the weight of the envelopes containing the root or shoot of individual okra plants. The weight of the total plant biomass (TPB) was determined by adding the actual weights of the roots and shoots.

Statistical analysis: The mean root and shoot weights including the TPB were analyzed using Analysis of Variance (ANOVA) and Duncan as Post Hoc test at 95% confidence level (i.e. P = 0.05).

RESULTS

Effects of simulated acid rain on the morphology of okra: For pH 1.0 treatment, all the replicates wilted 2 weeks after treatment (see **Fig. 1**). pH 2.0 treatment showed yellow colouration (chlorosis) and early leaf senescence (see **Fig. 2**). pH 3.0 treatment exhibited mild and marginal chlorosis with brown spots all over some of the leaves due to fungal infection (see **Fig. 3**). pH 4.0 treatment showed chlorosis, emerging black spots and white powdery growth all over some leaves due to fungal infection (see **Fig. 4**). pH 5.0 treatment showed normal leaf development (see **Fig. 5**). pH 6.0 treatment had dehydrated and wilted leaves while some others had white powdery growth on their leaf surfaces due to fungal attack (see **Fig. 6**). pH 7.0 treatment (control) showed normal leaf development (see **Fig. 7**).

A B

Figure 1: Morphological defects observed in pH 1.0 treatment

(A) Dead and disintegrated okra plant. (B) Dead okra seedling.

A B

Figure 2: Morphological defects observed in pH 2.0 treatment

(A) A replicate showing yellow colouration (chlorosis) on one of the leaves.
(B) All the leaves are lost (early leaf senescence) but two okra fruits with black colourations (due to pathogen infection) remain.

A B

Figure 3: Morphological defects observed in pH 3.0 treatment

(A) A replicate showing mild chlorosis with dark spots (due to fungal attack) scattered all over its leaf.
(B) An okra individual showing yellow colourations at the leaf margins (marginal chlorosis).

A B

Figure 4: Morphological defects observed in pH 4.0 treatment

(A) A replicate exhibiting chlorosis with emerging black spots on a leaf surface due to fungal infection.
(B) An okra leaf having white powdery growth on the leaf surface due to fungal infection.

A B

Figure 5: Morphological defects observed in pH 5.0 treatment

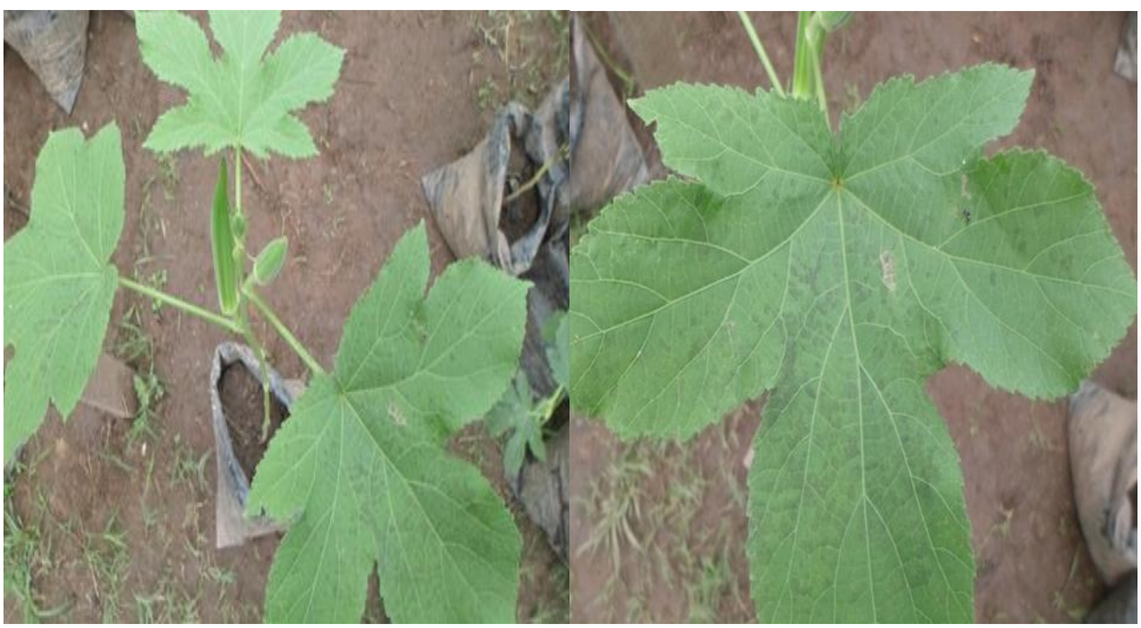
(A) A replicate showing normal leaf development.
(B) A healthy okra individual bearing a normal green leaf.

A B

Figure 6: Morphological defects observed in pH 6.0 treatment

(A) A completely dehydrated and wilted okra plant.

(B) An okra leaf with white powdery growth on the leaf surface due to fungal infection.



A B

Figure 7: Morphological defects observed in pH 7.0 treatment

(A) A replicate possessing healthy plant parts.

(B) A healthy okra individual having a normal green leaf colouration.

Effects of simulated acid rain on the phenology of okra: The effects of simulated acid rain (SAR) on the phenology of pH 1.0 treatment could not be determined as all the replicates wilted after 2 weeks of SAR application (see **Fig. 1**). pH 2.0 treatment showed chlorosis of the fruits and a black colouration (due to pathogen infection) on some fruits (see **Fig. 8**). pH 3.0 treatment exhibited mild chlorosis on okra fruits whilst some other fruits were healthy in appearance (green-coloured) (see **Fig. 9**). pH 4.0 treatments all had healthy green-coloured fruits (see **Fig.10**). pH 5.0 treatments all had healthy green-coloured fruits (see **Fig. 11**). pH 6.0 treatments had discoloured, dehydrated and wilted fruits whilst some other fruits had white-coloured rot-like appearance due to fungal infection (see **Fig. 12**). pH 7.0 treatments all had healthy green-coloured fruits (see **Fig. 13**).

A **B**

Figure 8: Phenological defects observed in pH 2.0 treatment

(A) An okra fruit exhibiting a yellow colouration (chlorosis) and wilting. (B) Okra fruits showing black colourations due to pathogen infection.

A **B**

Figure 9: Phenological defects observed in pH 3.0 treatment

(A) Slight yellow colouration (mild chlorosis) exhibited by an okra fruit.
(B) Okra fruit possessing the normal green colouration.

A **B**

Figure 10: Phenological defects observed in pH 4.0 treatment

(A) Two healthy-looking okra fruits. (B) A normal green-coloured okra fruit.

A **B**

Figure 11: Phenological defects observed in pH 5.0 treatment
(A) A normal green-coloured okra fruit. (B) A healthy-looking okra fruit.

A **B**

Figure 12: Phenological defects observed in pH 6.0 treatment

(A) Completely dehydrated and wilted okra fruits.

(B) Okra fruit showing white-coloured wet rot due to fungal infection.

A **B**

Figure 13: Phenological defects observed in pH 7.0 treatment

(A) A healthy-looking okra fruit. (B) Two green-coloured okra fruits growing normally.

Effects of acid rain on the yield (dry biomass) of okra: From the results obtained, it was observed that simulated acid rain (SAR) affected the yield (dry biomass) of okra. The highest mean root weight value (1.56g) was attained at pH 5.0 followed by pH 2.0 with 1.39g, pH 3.0 with 1.19g, pH 4.0 with 1.07g, pH 7.0 with 0.96g, pH 6.0 with 0.89g and pH 1.0 with the least value of 0.58g as shown in **Fig. 14**. However, there was no significant difference ($P<0.05$) among the treatments studied for the mean root dry biomass (see **Table 2**).

For the mean shoot dry biomass, pH 5.0 had the highest shoot weight value (6.32g), followed by pH 6.0 with 4.51g, pH 3.0 with 4.09g, pH 7.0 with 3.52g, pH 2.0 with 3.28g, pH 1.0 with 3.18g and pH 4.0 with the least mean shoot weight at 3.00g as shown in **Fig. 15**. However, there was no significant difference ($P>0.05$) between treatments pH 5.0 and 6.0, but they were both significantly different ($P<0.05$) from all other treatments (see **Table 2**).

For the total plant biomass (TPB) which is the combination of the root and shoot mean weight values of the okra, pH 5.0 had the highest TPB value (7.89g), followed by pH 6.0 with 5.40g, pH 3.0 with 5.27g, pH 2.0 with 4.67g, pH 7.0 with 4.48g, pH 4.0 with 4.07g, and pH 1.0 with the least TPB value at 3.76g as shown in **Fig. 16**. However, there was a significant difference ($P<0.05$) between pH 5.0 and all other treatments in terms of the TPB (see **Table 2**).

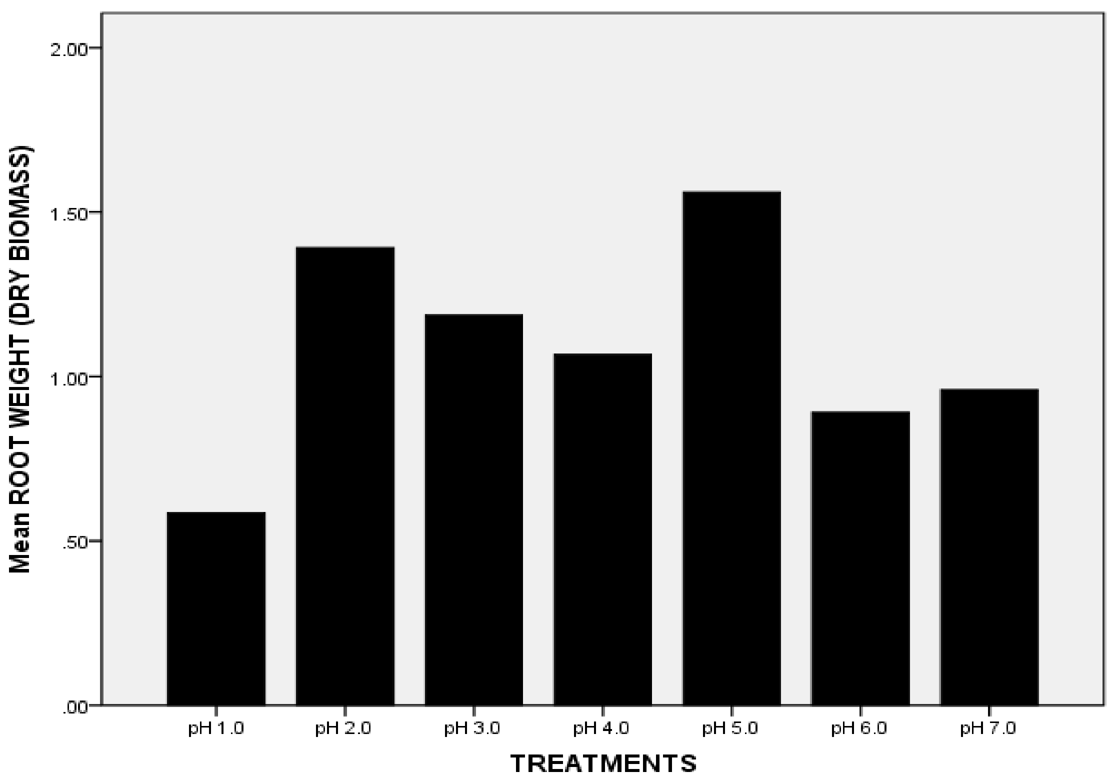


Figure 14: Effects of simulated acid rain on the root (dry biomass) of okra

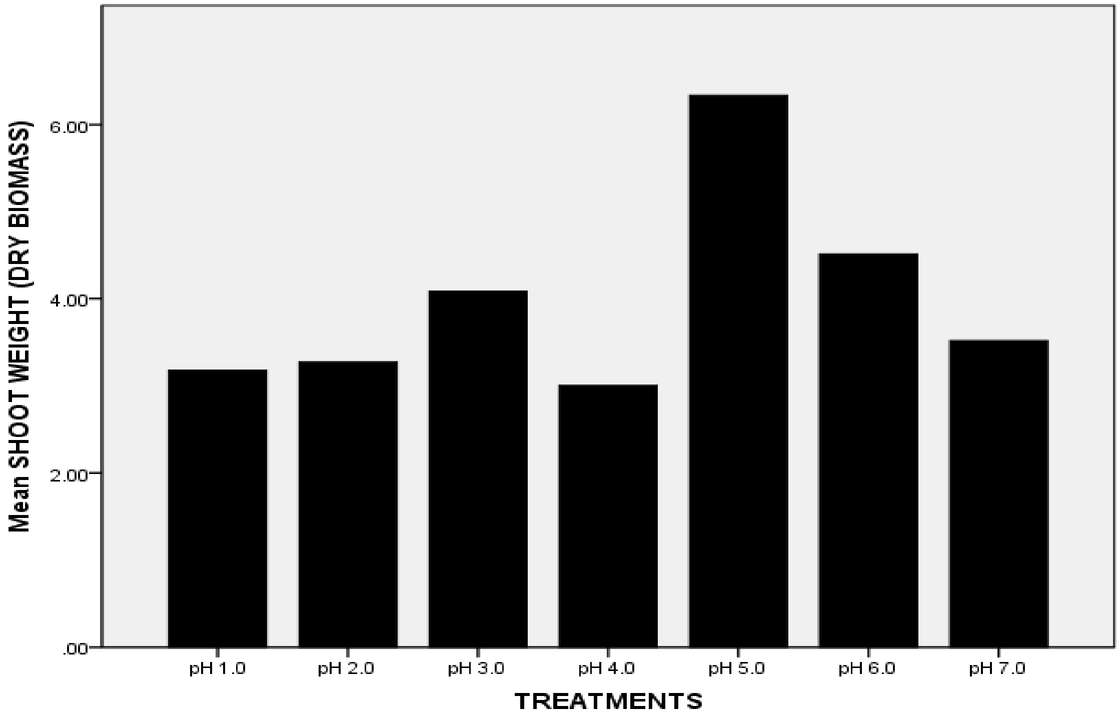


Figure 15: Effects of simulated acid rain on the shoot (dry biomass) of the okra

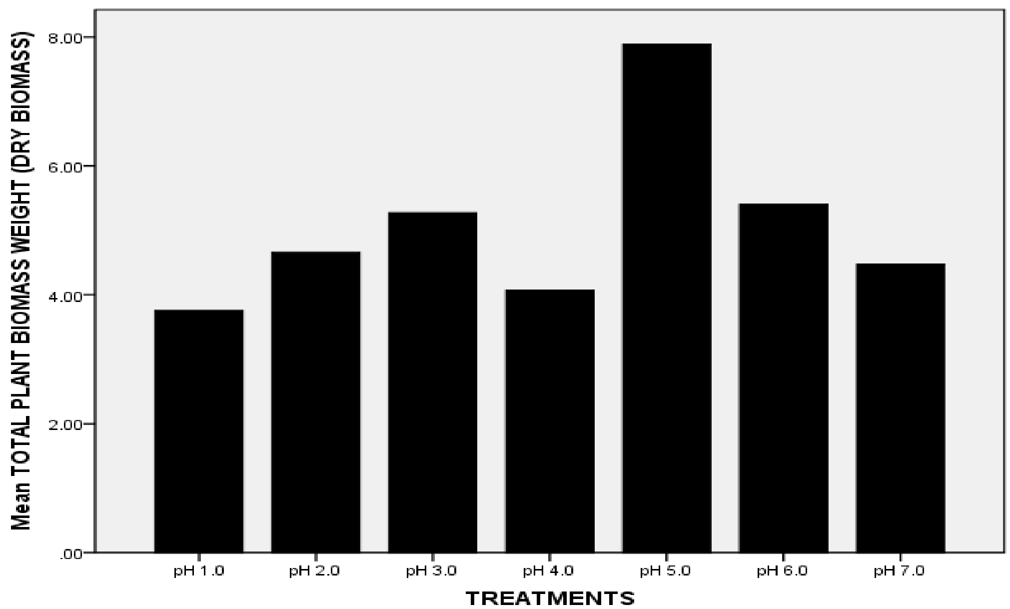


Figure 16: Effects of simulated acid rain on the total plant biomass (TPB) of okra

Table 2: Effects of SAR on the yield (dry biomass) of okra

Yield	pH 1.0	pH 2.0	pH 3.0	pH 4.0	pH 5.0	pH 6.0	pH 7.0
Root weight	$0.58^{a}\pm0.56$	$1.39^{b}\pm0.10$	$1.19^{ab}\pm0.22$	$1.07^{ab}\pm0.16$	$1.56^{b}\pm0.51$	$0.89^{ab}\pm0.20$	$0.96^{ab}\pm0.16$
Shoot weight	$3.18^{a}\pm0.64$	$3.28^{a}\pm0.57$	$4.09^{a}\pm0.62$	$3.01^{a}\pm0.21$	$6.32^{b}\pm1.25$	$4.51^{ab}\pm0.81$	$3.52^{a}\pm0.31$
Total Plant Biomass	$3.76^{a}\pm0.68$	$4.67^{a}\pm0.55$	$5.27^{a}\pm0.53$	$4.07^{a}\pm0.35$	$7.89^{b}\pm1.63$	$5.40^{a}\pm1.01$	$4.48^{a}\pm0.37$

Values are mean ± standard error. Values with the same alphabet within the same column are not significant (P>0.05)

DISCUSSION

Effects of simulated acid rain on the morphology of okra: It was observed that pH 1.0 treatments died barely 2 weeks after SAR application, indicating the inability of okra to withstand acid rain at such pH value as it could hasten complete dehydration, discolouration and wilting of the entire okra plant. pH treatments 2.0, 3.0 and 4.0 all exhibited chlorosis (either mildly, severely or marginally) of the okra leaves which is in support of the reports of Silva *et al*.[16] and Odiyi and Bamidele[27] who concluded that plants exposed to low pH rain will generally exhibit leaf chlorosis and dehydration as part of their morphological defects. Similarly, chlorotic leaf damage in okra was also reported by Shaukat and Khan[25]. Furthermore, fungal infections triggered by SAR were observed on the okra leaves. In Figures 3A and 4A (for pH 3.0 and 4.0), dark spots were found all over the top surface of the okra leaves indicating a possible attack by the black mould, *Cercospora abelmoschi*, which has a similar characteristic effect on okra leaves[28]. In Figures 4B and 6B (for pH 4.0 and 6.0), white powdery growth covered the okra leaf surface indicating a possible attack by the powdery mildew, *Oidium asteris-punicei*, which has a similar characteristic appearance on okra leaves[28,29]. The SAR-induced fungal attack on the leaves is in accordance with the conclusions of Evans[30], Percy[31] and Khan and Khan[32] that some plant species mostly vegetables treated with SAR often show signs of fungal attack. Similarly, Bolla and Fitzsimmons[33] and Shaukat and Khan[25] reported that acid rain has the potential to alter the leaf physiology of some plants thereby, rendering the plants susceptible to pathogen attack. However, pH treatments 5.0 and 7.0 possessed healthy green-coloured okra leaves thus, appeared to be resistant to SAR application.

Effects of simulated acid rain on the phenology of okra: The earliest flower emergence time (i.e. on the 9th week: 63 days after planting) was observed in at least one replicate of all the pH treatments studied except in pH treatments 1.0 and 4.0 (see **Table 1**). Only pH 6.0 had up to three replicates emerging flowers that early. pH 1.0 okra plants died 2 weeks after SAR application, therefore had no phenological importance. As for pH treatment 4.0, its first flowers emerged late on the 11th week (i.e. 77 days after planting). According to Sulikiri and Swamu[34] okra plants initiate flowering between 41 and 48 days (i.e. about 7 weeks) after planting. Therefore, the delay in flower emergence by 2 weeks observed in this study may be as a result of the okra variety (NH-34) used and not due to SAR application. Fruit emergence occurred one day after flower emergence for all the pH treatments studied. The number of fruits produced by the treatments was approximately the same (1-2 fruits per stand). However, some treatments that developed fruits early such as pH 6.0, wilted before the experiment was terminated (see **Fig. 12**). Similar to the morphological defects in okra leaves, the okra fruits also exhibited chlorosis, dehydration, wilting and pathogen infection as they developed. pH treatments 2.0 and 3.0 had fruits showing chlorosis while pH 6.0 was completely dehydrated and eventually wilted. SAR-induced pathogen attack was also observed in the okra fruits. In Figures 2B and 8B (for pH 2.0), black colouration of the okra fruits occurred together with the total loss of leaves, indicating a possible bacterial blight (*Xanthomonas axonopodis p.v. vignicola*) attack which has a similar appearance on okra fruits[29]. In Fig. 12B (for pH 6.0), the okra fruit had white-coloured rot-like appearance indicating a possible attack by a wet rot fungus[28]. However, pH treatments 4.0, 5.0 and 7.0 all had healthy green-coloured okra fruits, which indicate SAR resistance.

Table 1: Treatments showing time of first flower emergence after SAR application

pH	Time of first flower emergence (in weeks)
1.0	None (All the replicates wilted)
2.0	Replicate 4 on week 9
	Replicate 3 on week 9
	Replicates 1 and 2 on week 10
3.0	Replicates 2 and 3 on week 9
	Replicates 1 and 4 on week 12
4.0	Replicates 1, 2 and 4 on week 11
	Replicate 3 on week 14
5.0	Replicate 2 on week 9
	Replicate 1 on week 12
	Replicates 3 and 4 on week 13
6.0	Replicates 1, 3 and 4 on week 9
	Replicate 2 on week 12
7.0	Replicate 1 on week 9
	Replicates 2 and 3 on week 10
	Replicate 4 on week 13

Effects of simulated acid rain on the yield (dry biomass) of okra: According to Singh and Agrawal[35], plants are likely to experience a reduction in biomass when treated with SAR as a result of inhibited photosynthetic activities. Therefore, the results on SAR effects on okra revealed the pH treatments most sensitive to SAR and that most resistant to SAR in terms of the root, shoot and total plant biomass (TPB) of okra. There was no significant difference ($P>0.05$) among the treatments studied for the mean root weight, which indicates that the use of the dry biomass of the root is an unreliable growth parameter in measuring the effects of SAR on okra. For the mean shoot weight, pH 5.0 and pH 6.0 seem to have similar values as there was no significant difference ($P>0.05$) between them but they were both significantly different ($P<0.05$) from all other treatments. However, pH 5.0 treatment appears to be more resistant to SAR than pH 6.0 treatment, because the latter had morphological and phenological defects despite its impressive shoot dry biomass accumulation while the former possessed healthy leaves and fruits. For the TPB, pH 5.0 treatment had the highest mean TPB and was also significantly different ($P>0.05$) from all other treatments which indicates that the okra plant (NH-34 variety) is most resistant to SAR at pH 5.0 in terms of root, shoot and TPB.

CONCLUSIONS

Based on the observations and results obtained from this research, it can be concluded that the SAR-induced morphological and phenological defects in okra include chlorosis, dehydration, wilting, early leaf senescence and death. In addition, is the opportunistic growth of pathogens; the suggested culprits include *Cercospora abelmoschi*, powdery mildew, bacterial blight and wet rot fungus, which festered on the leaves and fruits of okra. There is no record on the flowering time of the okra variety (NH-34) used for this study therefore, the delay in flowering observed may actually be unique to the okra variety utilized for this study. Incidentally, this study presents the first SAR-induced phenological defects in okra. It can be deduced from the study that the pH range in which okra is resistant to SAR treatment is from 7.0 to 5.0, however, okra appeared to be most resistant to SAR particularly at pH 5.0 in terms of morphology, phenology and yield. Since the pH range of rain for the normal growth of okra is between 6.0 and 6.8[6], this study has clearly shown that a further reduction in pH to 5.0 will not have any significant effect on okra's morphology, phenology and yield. However, a continuous reduction (pH 4.0, 3.0, 2.0 and 1.0) in the pH will impact the okra plant negatively. The effects of SAR on okra were therefore, expressed in the following order of severity: Morphology >Yield > Phenology.

With the increasing global preference for societal urbanization, industrial processes that release acidic gases (SO_2 and NO_2) into the atmosphere may be very difficult to control. Consequently, okra which is a widely-grown vegetable in the Tropics and generally known for its medical importance is expected to be threatened over time if the anthropogenic sources of acid rain formation are not managed effectively. Acid deposition has the potential to reduce the yield and market value of important Tropical vegetables, thereby threatening food security in the Tropics. Therefore, it may be expedient to execute the following: Educate the local and international communities on the negative impacts of burning fossil fuel which emits gases that result in acid depositions; factories and industries should devise a means of safely collecting the gases emitted from their plants so that it does not contaminate the atmosphere; vehicles that do not emit oxides of sulphur and nitrogen should be produced in commercial quantities and made relatively affordable; more varieties of okra plant or other tropical vegetables should be investigated for their tolerance to acidic deposition; subsequent SAR studies on okra should consider identifying the pathogens that attack okra due to SAR treatments to possibly corroborate the suggested culprits stated in this study.

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