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Relationship between Micro-Climatic Parameters and Atmospheric Pollutants at Selected Road Junctions in Port Harcourt. Niger Delta, Nigeria

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Abstract:
The increase in vehicular activities has led to the proliferation of atmospheric pollutants in industrialized cities worldwide. This study postulates that there will be a relationship between micro-climatic parameters and atmospheric pollutants. Samples were collected from five locations selected within Port Harcourt, namely Choba Junction, Rumuokoro Junction, Garrison Junction, Mile 3/UST roundabout, and Lagos Bus Stop. The measured parameters are air temperature, relative humidity, wind speed, nitrogen dioxide (NO2), sulfur dioxide (SO2), carbon monoxide (CO), and suspended particulate matter (SPM). The results showed that the mean concentration of carbon monoxide (CO) ranged between 13 ppm to 27.2 ppm. Sulfur dioxide and nitrogen concentrations were below the detection limit. Choba has the highest SO2 (0.6 ppm) and NO2 (0.02 ppm) concentrations. Mornings had the highest concentration of pollutants compared to evenings. Similarly, the mean concentration of PM2.5 ranged between 71.4µg/m to 162.6 6µg/m3. For the micro-climatic, the mean temperature ranged from 25.6°C to 33.7°C, mean relative humidity ranged from 50.6% to 87.3%, and wind speed ranged from 0.8m/s to 1.4m/s. Higher micro-climatic values were also recorded at Choba. The relationship between atmospheric pollutants and particulate matter with microclimatic parameters was not significant (P>0.05). But in contrast, there was a relationship between temperature and relative humidity with the concentrations of PM2.5 and PM10 (P<0.05). The result implies that locations with high micro-climatic parameters have the possibility of having higher concentrations of atmospheric pollutants. Thus, constant monitoring of the emission level of vehicles is essential.

Keywords: air pollution, climate, particulate matter, temperature, emission, vehicle, Port Harcourt

INTRODUCTION

Air Pollution is defined as the emission of toxic chemical particles or biological components into the atmosphere with the capacity to cause a wide range of damage to living organisms and the environment. Transportation engines, industrial processes and burning of municipal waste materials have been identified as the major sources of air pollution (Sharma et al, 2013). The environment has kept on experiencing pollution because of the expanding populace and increased industrialization. Increased industrialization has had a negative toll on the environment as emissions from several industrial plants have contributed to the deteriorating air quality of urban areas (Goel, 2009). Reports have shown that motor vehicles account for 51% of carbon monoxide emissions annually, 34% of nitrogen dioxide and 10% of particulate matter released in the United States (USEPA, 2006). On a regional level, Naude et al, (2000) revealed that road transportation significantly contributed to the elevated levels of carbon dioxide in the atmosphere in South Africa.

The pollutants released from vehicles include carbon dioxide, carbon monoxide, sulphur oxide, nitrogen oxide, particulate matter, hydrocarbons and lead (Corbitt, 1999). It is feared that, if these pollutants are not monitored, they may so alter the environment as to endanger even human existence on the planet. For example, through deposition, air pollutants contaminate food and have also led to many respiratory diseases, asthma, chronic obstructive pulmonary disease and cancer of the lungs (Erica, 2009). Moreso, air pollutants travel long distances chemically reacting in the atmosphere to produce secondary pollutants such as ozone and other greenhouse gases (Enemari, 2001).

Air quality as defined by Wark and Warner (2002) is term used to describe air conformance to required standards. There are a set of requirements regarding the quality of air (usually related to concentrations of various chemical parameters and constituents of air). Air quality is therefore a term that implies some value judgment of the air with respect to its use. Any change in the natural air quality implies pollution. According to AIHA (2002) poor air quality can manifest itself aesthetically as a displeasing odour. The study of Nang and Etahir (2002) revealed that rainfall increases as CO_2 levels rise. However, the findings of Held et al. (2005) negate the earlier findings of Nang and Etahir (2002). Held et al. (2005) using new global climate models predicted a significantly drier sahel guinea savannah as a result of the increase in CO_2 concentration and other greenhouse gases. Kim et al. (2001) investigated diurnal behavior and exceedance patterns of air quality criteria, ozone (O_3), and nitrogen dioxide (NO_2) in Seoul and showed that their behavior is strongly linked with geographical and meteorological factors.

Choi et al. (2008) found a possible relationship between cloud formation and PM_{10} on weekly timescales when studying the interaction between PM_{10} and the meteorological parameters in the boundary layer over China. Lee et al. (1999) found that the annual mean SO_2 concentration in Seoul was higher than in Hamilton, Canada, and lower than in Chicago yet with the highest values during the winter season in Seoul, which is consistent with the high winter-time fuel usage. Many studies indicated that TSP and PM_{10} concentration in ambient air is affected by wind speed, wind direction, solar radiation, relative humidity and rainfall (Monn, 2001). Temperature affects fuel usage and ambient chemical reactions; radiation sets up photochemical reactions with other pollutants; precipitation and relative humidity largely removes pollutants from the atmosphere (Seinfeld and Spyros, 1998).

The observance of seasonal variation in PM10 concentrations should be partially attributable to changes in the meteorological conditions. The variation in mean PM10 concentrations noted at different sites in a Kathmandu Valley suggests influence of climate particularly the rain (Giri et al., 2006). Elevated PM_{10} concentrations occur during the period when temperatures fall, particularly during the morning times when traffic commutation is heavy. It could also be seen in the results that precipitation and wind velocity probably is of greater importance and has a stronger connection to PM_{10} concentrations in Kathmandu valley (Giri et al., 2008). In general, diffusion and transport of pollutants are determined by atmospheric conditions such as wind speed, vertical temperature gradient, and solar radiation. With increase of rainfall and humidity the PM_{10} concentration decreases (Seinfeld and Spyros, 1998). A combination of meteorological variables important to these conditions includes temperature, winds, radiation, atmospheric moisture, and mixing depth (Beaver & Palazoglu, 2009). Meteorological conditions play a crucial role in ambient air pollution by affecting both directly and indirectly the emissions, transport, formation, and deposition of air pollutants. Several research studies pertaining to weather and atmospheric pollution effects on humans have established associations between meteorological conditions and parameters to air pollutants. These studies have provided evidence that meteorological factors such as wind velocity and direction, temperature and relative humidity can significantly affect air quality (Elminir, 2005). The most important role of meteorology is in the dispersion, transformation and removal of air pollutants from atmosphere. Also, adverse health consequences of ambient ozone pollution increase when temperatures are higher (Jacob and Winner, 2009)

Empirical studies revealed that fine particles are controlled mainly by wind and temperature and 60% to 74% day-to-day variation of particulate matter concentrations can be reasoned by meteorological parameters and that any change of the concentration of $PM_{2.5}$ is well related to pressure, relative humidity, and wind speed (Hien et al., 2002).

Air pollution is affected by multiple factors, including pollutant emissions, meteorological conditions, terrain, pollutant transport, and transformation (Zhang et al, 2019). The study of Liu et al. (2019) revealed that both pollutant emissions and meteorological conditions dominated pollutant concentration trends. Beside emission control, favorable meteorological conditions have significant impacts on air quality by determining dispersion conditions and thus atmospheric environmental capacity (Meng et al, 2019). Furthermore, weather conditions (e.g., temperature and relative humidity) also play an important role in chemical reactions, and then change the reacted pollutant concentrations (Li et al., 2019). He et al. (2017) reported that more than 70% of the daily concentration variation over China could be explained by the meteorological conditions. Okoroafor & Ikebude (2015) revealed in their research that a statistically significant relationship exists between the concentration of atmospheric pollutants studied and the prevailing meteorological factors. This is so, because total dispersion of the pollutant (CO, SO_2 and NO_2) was completely explained by meteorological factors (Wind speed, Air temperature, and Relative Humidity). In Port Harcourt (which is a part of the Niger Delta), much attention has been given to industrial pollution and pollution in oil companies to the neglect of the increasing damage caused by pollution from mobile transportation sources (Magbabeola, 2001). The study is aimed at determining the relationship between micro-climatic parameters and atmospheric pollutants and particulate matter at different locations.

MATERIALS AND METHODS

Study Area

Port Harcourt is the capital of Rivers State. It is the main city in the state and has the one of the largest seaports in the Niger Delta region of Nigeria. It is the hub of industrial, commercial, administration and other activities in the state. The city lies between latitude 04^{o} 43′ and 04^{o} 57′ North of the Equator and between 06^{o} 53′ and 07^{o} 08′ East of the Greenwich Meridian. The city is surrounded by patches of islands and creeks of the Niger Delta. It is approximately 60km from the crest up stream of the Bonny River and covers an estimated area of 1811.6 square kilometers (Obafemi, 2006). The map of Rivers State showing Port Harcourt metropolis and map of Port Harcourt metropolis is represented in Figures 1 and 2 respectively.

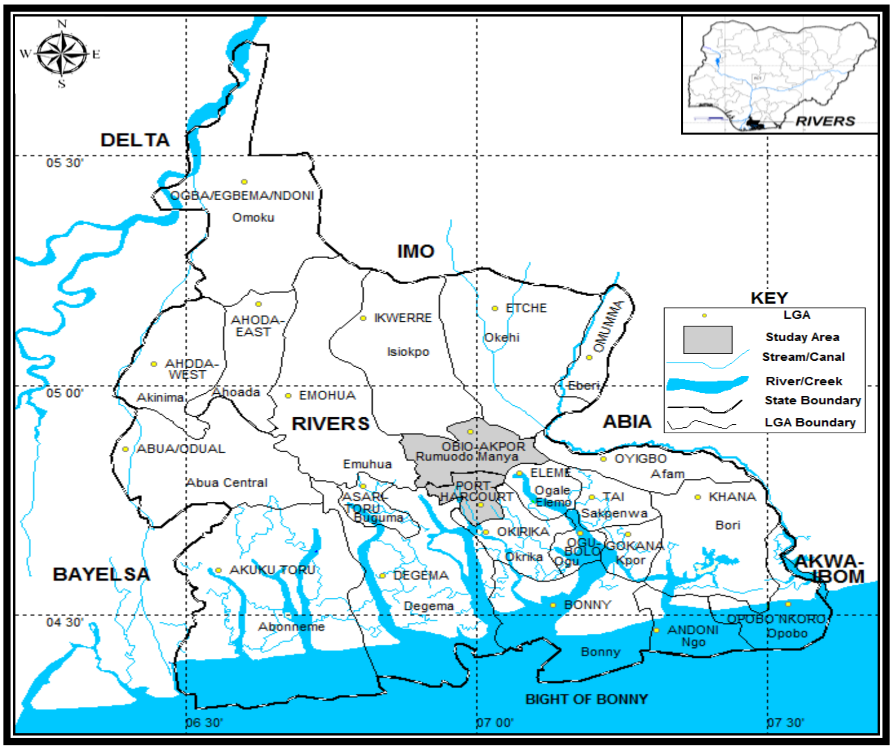

Figure 1: Map of Rivers State Showing Port Harcourt Metropolis

(Source: Cartography/GIS Laboratory, Department of Geography and Environmental Management, University of Port Harcourt, Choba)

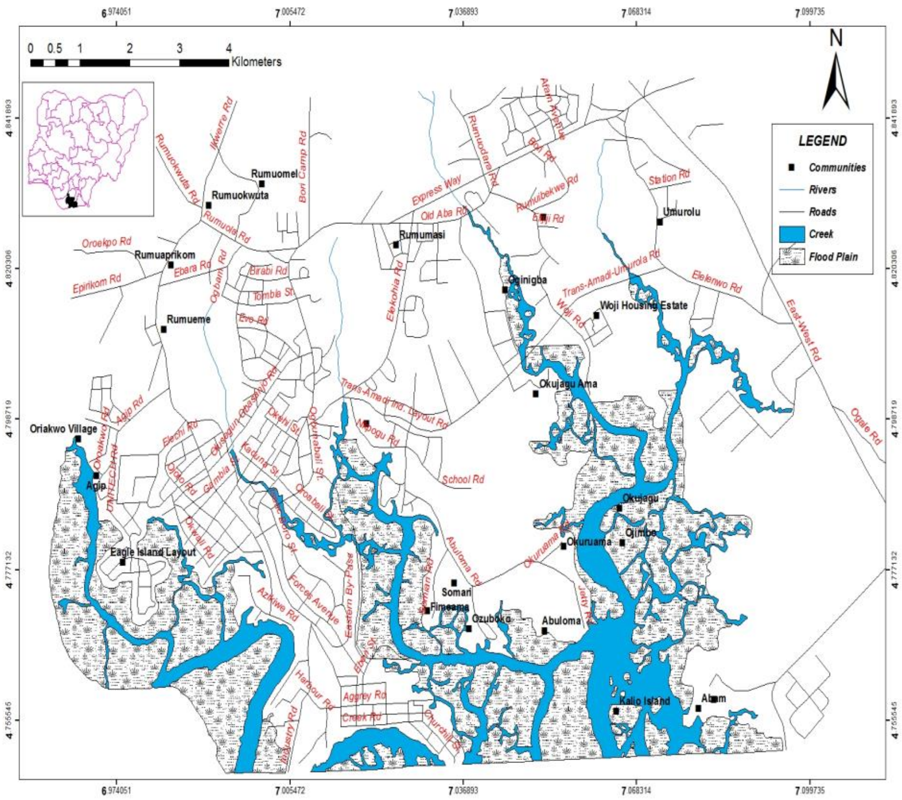

Figure 2. Map of Port Harcourt Metropolis

(Source: Cartography/GIS Laboratory, Department of Geography and Environmental Management, University of Port Harcourt, Choba).

Climate:

Port Harcourt has a tropical hot monsoon climate with heavy rainfall and high temperature all year round. Similarly, its geographical contiguity to the Atlantic Ocean is one of the reasons for the heavy rainfall (Osuiwu and Ologunorisa, 1999). The mean annual rainfall ranges from 2000mm to over 4000mm. The rainy season starts from April through October and peaks in July and September with a break in August. However, this period of August break has been fluctuating in recent times due to the ever-changing climate (Mmom, 2003). Relative humidity is high throughout the year while the diurnal temperature ranges between 25^{o}C and 30^{o}C (Ashton, 1998). Harmattan season occurs between late November and March and is accompanied by a dry dusty wind (Mmom, 2003).

Soils:

The city has a top soil layer of soft mud of about 6m thick having high organic materials in the delta area and a relatively high-water table. The superficial soils of the region consist of reddish-brown sand clay loam; brown sandy soil; light gray slightly organic fine sand soils; silty clay and dark organic clay soils (Obafemi, 2006, Oyegun, 1999). Nitrogen and potassium are the most deficient minerals in the soils of the area because of severe leaching due to the heavy rainfall (Wizor, 2012).

Relief and Drainage:

The relief of the area is low lying and the rivers are prompted by tidal fluctuation (Wizor, 2012). The area falls within the coastal belt dominated by low-lying coastal planes which structurally belong to the sedimentary formations (Umeuduji and Asuebogun, 1999), and barrier ridge (Izeogu and Aisuebegun, 1989).

Economic Activities:

Port-Harcourt is the hub of Nigeria's oil industry, has numerous extractive industries such as mining of coal, tin and petroleum, oil and gas liquefaction, which are among the economic activities in the city (Gafar, 2016). It also has private businesses (Alloh, 2018).

Sample And Sampling Techniques

The sample size includes five locations selected within Port Harcourt. The selected locations include Choba Junction, Rumuokoro Junction, Garrison Junction, Mile 3/UST roundabout and Lagos Bus Stop. The purposive sampling technique was deployed to select the five road traffic junctions within the city. The selection criterion is that each sampling site must be a high traffic density road junction.

Methods of Data Collection:

The parameters that were measured include air temperature, relative humidity, wind speed, nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and suspended particulate matter (SPM).

Micro Climatic Parameters:

Wind Speed (m/s):

A Digital Anemometer (Taylor wind scope) was used to measure the wind speed in meters per second (m/s). This portable equipment measures the wind speed once it is switched on and held in position.

Air Temperature (°C):
The air temperature in degrees Celsius (°C) was measured with a hand-held digital thermometer. The thermometer was carefully arid safely removed from the pouch and exposed to the air for a few minutes in the respective sampling positions. The temperatures were then read off and recorded.

Relative Humidity (%):
A logger (Testo 450) was used in determining the relative humidity. The logger is equipped with an atmospheric pressure probe (Barometer) and a relative humidity probe (Hygrometer). The logger measures and stores the value in percentage (%).

Air Quality:
Sampling and measurements of the chemical constituents of atmospheric pollutants was carried out in-situ with hand-held air quality monitors described below:

- **Nitrogen Dioxide (NO_2):** A multi–RAE PLUS (PGM-50), a programmable Multi Gas monitor with an electrochemical sensor was used for the detection of NO_2. The range of detection is between 0-20ppm with a resolution of 0.olppm. The alarm set point (low/high) was set at 2 and 10ppm respectively. Measurements were taken by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind and readings recorded at stability.
- **Sulphur Dioxide (SO_2):** A multi–RAE PLUS (PGM-50), a programmable Multi Gas Monitor with an electrochemical sensor was used for the detection of SO_2. The range of detection is between 0-20ppm with a resolution of 0.olppm. The alarm set points (low/high) was set at 2 and loppm respectively. Measurements were taken by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind and readings recorded at stability.
- **Carbon Monoxide (CO):** An ELE Analox Sensor Gas Monitor Model GC 401 was used for the detection of CO. The equipment detects CO via an electrochemical sensor that generates a signal linearly proportional to the concentration of the gas. The range of detection is between 0-500ppm and the limit of detection is lppm. Measurements were taken by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind and readings recorded at stability.
- **Suspended Particulate Matter (SPM):** A Met One Instrument, Inc Aerosol Mass Monitor was used to measure suspended Particulate matter (SPM). This Ambient particulate Monitor with recorder collects and records "real-time" information on airborne particulate concentration in addition to providing continuous particle monitoring. A laser optical sensor for detecting and measuring particulate concentration up to 1 milligram per cubic meter is included. Measurements were taken by holding the equipment to a height of about 1.5 meters in the direction of the prevailing wind and readings recorded at stability.

Measurement was collected at each selected location for the morning peak period (7:00-9:00am) and an evening peak period (5:00-7:00pm) daily over a period of five days. The traffic flow pattern is an uninterrupted traffic flow; hence the measurements were taken at the median of the road for a double carriage way and at the side of the road for a single carriage way. All measurements were taken at a height of 1.5 meters above ground level which is the average height of a person exposed to pollution from traffic sources. The wind speed, temperature and Relative humidity will be taken simultaneously with the other parameters.

Statistical Analysis
The study utilized quantitative techniques in data presentation and analysis. Mean values for the selected road junctions were computed and presented in tables and charts. Hypothesis 1 stated for the study, was tested using the One-way ANOVA. The variations that exist in different parameters studied were computed in order to determine the spatial variation of each parameter across the selected road junctions in the study area. Hypothesis 2 stated for the study was tested using the Pearson Product Moment Correlation (PPMC) Statistics. This was performed in order to show the relationship between meteorological conditions and atmospheric pollutants observed at the selected road junctions. The computer software used for the statistical analysis is known as Statistical Package for Social Sciences (SPSS), version 21.

RESULTS
Concentration Levels of Carbon Emission and Micro-climatic Parameters
Table 1 below reveals the mean concentration levels of carbon emission at selected road junctions during the morning and evening peak periods. The results showed that the mean concentration of carbon monoxide ranged from a lowest of 13ppm at Lagos Bus Stop in the morning to a highest of 27.2ppm at Rumuola Bus Stop in the morning. Sulphur dioxide concentration was below detection limit at Lagos Bus Stop while the highest concentration was observed at Choba junction with a concentration of 0.6ppm. Nitrogen oxide concentration was below detection limit at all the selected road traffic junctions except for Choba Junction which recorded a mean concentration of 0.02ppm. Generally, the concentration levels of the emission were higher in the morning peak periods than in the evening peak periods except for the carbon monoxide concentrations of Mile 3/ UST Roundabout and Lagos Bus Stop.

Table 1: Mean Concentration Levels of carbon exhaust emission

Study Locations	Time	Carbon Monoxide (ppm)	Sulphur dioxide (ppm)	Nitrogen oxides (ppm)
Choba Junction	Morning	24.8	0.6	0.02
	Evening	17.2	0.2	0.00
Rumuola Bus Stop	Morning	27.2	0.2	0.00
	Evening	17	0.2	0.00
Garrison Bus Stop	Morning	19.8	0.0	0.00
	Evening	15.8	0.4	0.00
Mile 3/ UST Roundabout	Morning	21.6	0.25	0.00
	Evening	22.8	0.2	0.00
Lagos Bus Stop	Morning	13	0.0	0.00
	Evening	17.8	0.0	0.00

Source: Researcher's Field Analysis (2021)

Table 2 below reveals the mean concentration levels of particulate matter at selected road junctions during the morning and evening peak periods. The results showed that the mean concentration of $PM_{2.5}$ ranged from a lowest of 71.4µg/m^3 at garrison bus stop in the evening to a highest of 162.6µg/m3 at choba junction in the morning. The results also showed that the mean concentration of PM_{10} ranged from a lowest of 78.2µg/m^3 at garrison bus stop in the evening to a highest of 174.4µg/m^3 at choba junction in the morning. Generally, the concentration levels of the particulate matter were higher in the morning peak periods than in the evening peak periods.

Table 2: Mean Concentration Levels of Particulate Matter

Study Locations	Time	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
Choba Junction	Morning	162.6	174.4
	Evening	76.4	91.8
Rumuola Bus Stop	Morning	116.6	138
	Evening	75	87.6
Garrison Bus Stop	Morning	122.4	129.4
	Evening	71.4	78.2
Mile 3/ UST Roundabout	Morning	98.7	115.4
	Evening	88.2	102.4
Lagos Bus Stop	Morning	90.8	101
	Evening	77.4	86.4

Source: Researcher's Field Analysis (2021)

Table 3 below reveals the prevailing micro-climatic conditions of the study locations during the morning and evening peak periods. The results showed that the mean temperature ranged from a lowest of 25.6°C at choba junction in the morning to a highest of 33.7°C at Lagos Bus Stop in the evening. The results also showed that the mean relative humidity at the selected study locations ranged from a lowest of 50.6% Mile 3/ UST Roundabout in the evening to a highest of 87.3% at choba junction in the morning. Moreso, the mean value of windspeed ranged from a lowest of 0.8m/s at choba junction in the morning to a highest of 1.4m/s at Mile 3/ UST roundabout in the morning. Generally, temperature was higher in the evening than in the morning while relative humidity values were higher in the morning.

Table 3: Prevailing Micro-Climatic Conditions of Selected Locations

Study Locations	Time	Temperature (°C)	Relative Humidity (%)	Windspeed (m/s)
Choba Junction	Morning	25.6	87.3	0.8
	Evening	30.9	63.4	1.1
Rumuola Bus Stop	Morning	27.4	83.1	1.0
	Evening	32.2	58.3	1.1
Garrison Bus Stop	Morning	29.6	79.1	1.3
	Evening	33.4	56.2	1.3
Mile 3/ UST Roundabout	Morning	28.8	80.7	1.4
	Evening	34	50.6	1.3
Lagos Bus Stop	Morning	30.3	76.8	1.1
	Evening	33.7	53.9	1.0

Source: Researcher's Field Analysis (2021)

Spatial Variation of Exhaust Emissions and Suspended Particulate Matter

The analysis of the spatial variation of carbon monoxide is revealed in Figure 3 below which reveals that the mean concentration of carbon monoxide was highest at Mile 3/ UST roundabout and Rumuola bus stop while the least concentration of carbon monoxide was recorded at Lagos bus stop.

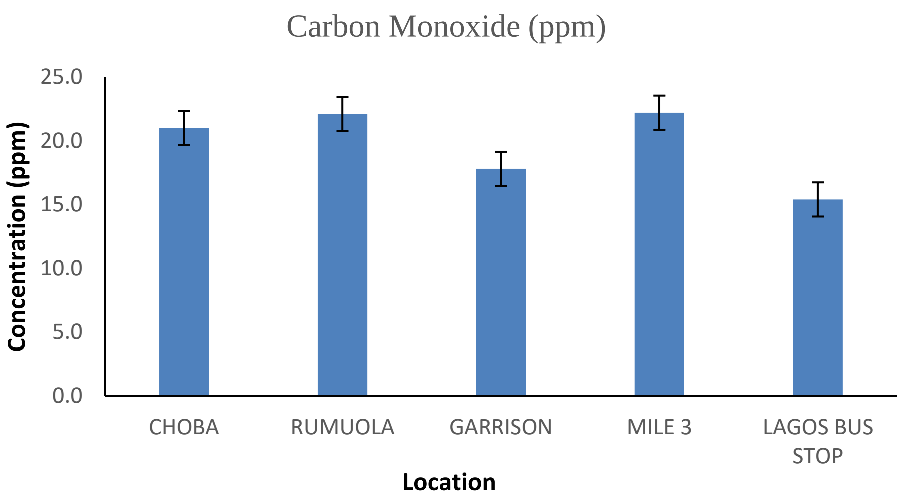

Figure 3: Spatial Variation of Carbon Monoxide at different locations in the Niger Delta, Nigeria

The analysis of the spatial variation of sulphur dioxide is revealed in Figure 4. The mean concentration of carbon monoxide was highest at Choba junction while the concentration of sulphur dioxide at Lagos bus stop was below detection limit.

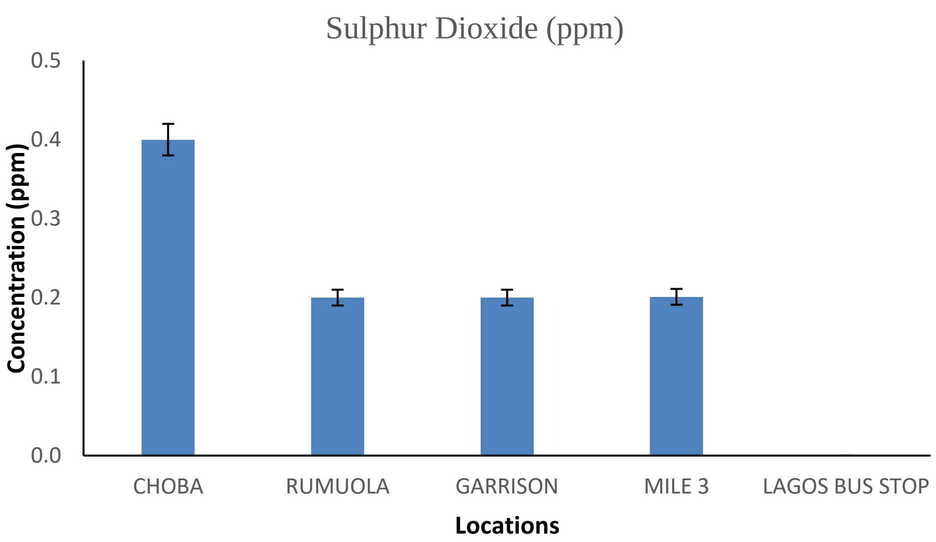

Figure 4: Spatial Variation of Sulphur dioxide at different locations in the Niger Delta, Nigeria.

The analysis of the spatial variation of nitrogen oxide is revealed in Figure 5. The mean concentration of nitrogen oxide was highest at Choba junction while the concentrations of nitrogen oxide at the other locations were all below detection limit.

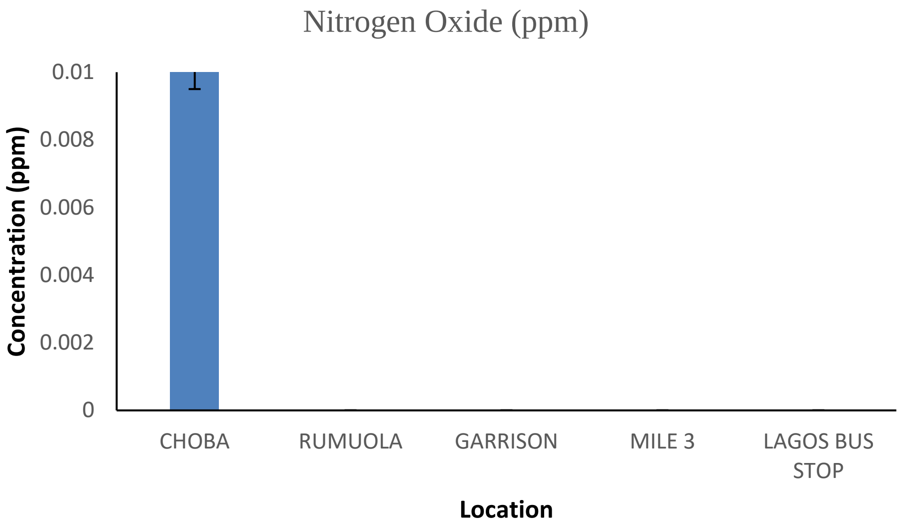

Figure 5: Spatial Variation of Nitrogen Oxide at different locations in the Niger Delta, Nigeria.

The analysis of the spatial variation of $PM_{2.5}$ is revealed in Figure 6. The mean concentration of $PM_{2.5}$ was highest at Choba junction while the lowest concentration of $PM_{2.5}$ was recorded at Lagos Bus stop.

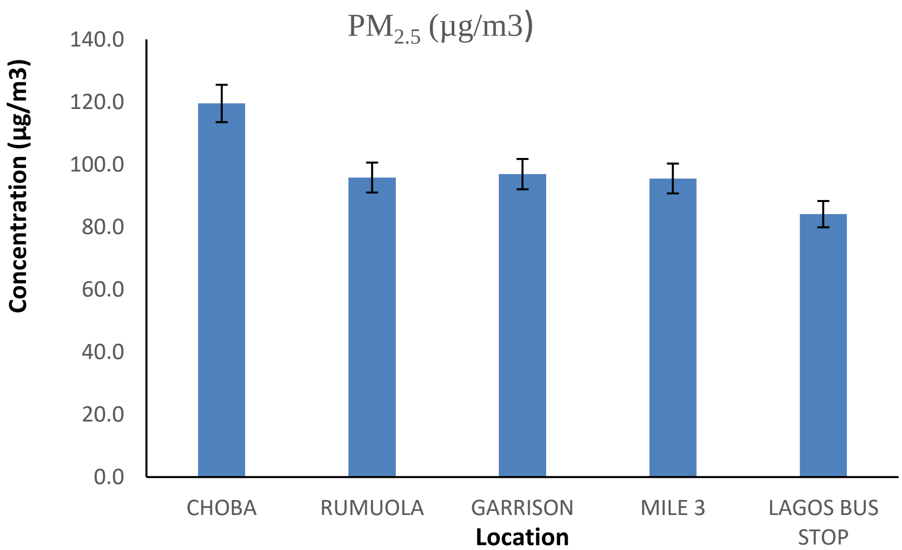

Figure 6: Spatial Variation of $PM_{2.5}$ at different locations in the Niger Delta, Nigeria.

The analysis of the spatial variation of PM_{10} is revealed in Figure 7. The mean concentration of PM_{10} was highest at Choba junction while the lowest concentration of PM_{10} was recorded at Lagos Bus stop as shown below.

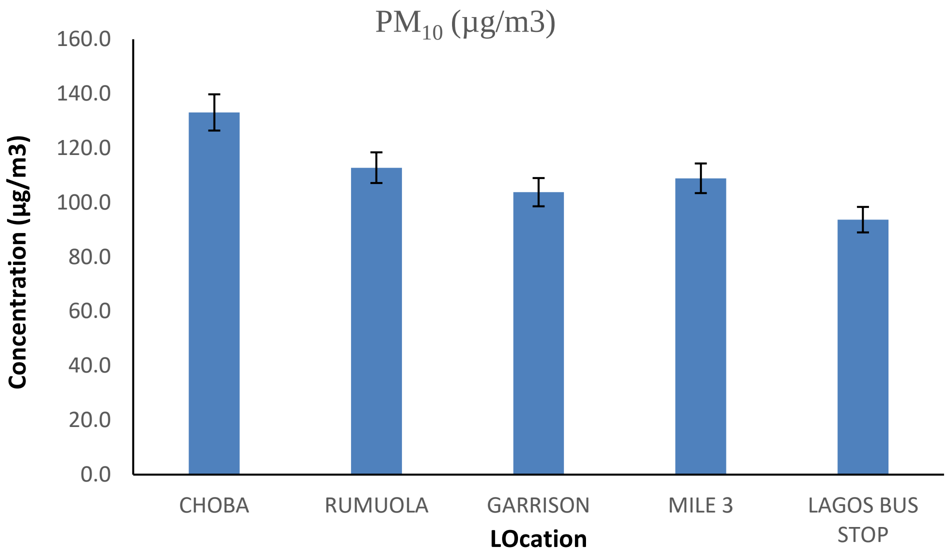

Figure 7: Spatial Variation of PM_{10} at different locations in the Niger Delta, Nigeria.

Evaluation of Micro-climatic Parameters at Selected Road Junctions

The analysis of temperature at selected locations is revealed in Figure 8. The mean temperature ranged from a lowest of 25.6°C at choba junction in the morning to a highest of 33.7°C at Lagos Bus Stop in the evening (Table 3). Similarly, Figure 7 also revealed that the mean temperature was highest at Lagos Bus Stop while the lowest was recorded at Choba junction

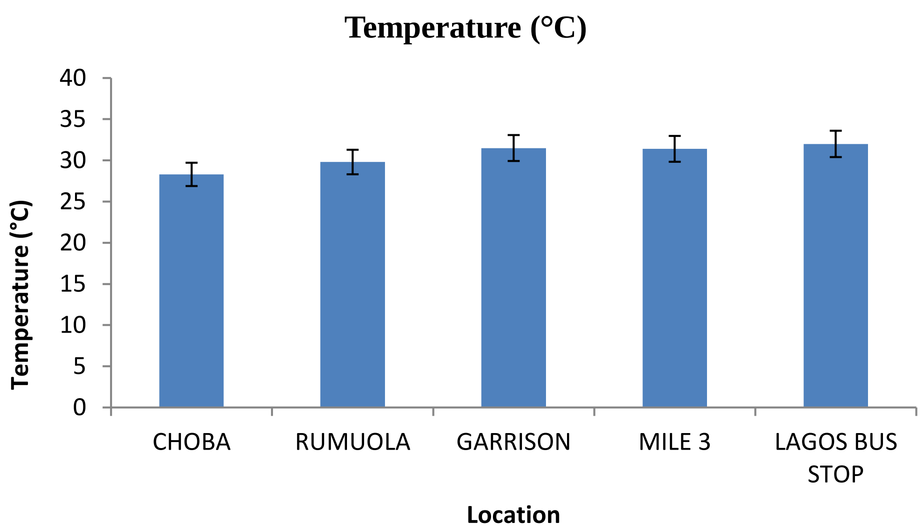

Figure 8: Mean Temperature of Selected Locations at different locations in the Niger Delta, Nigeria.

The analysis of relative humidity at selected locations is revealed in Figure 9. The mean relative humidity was highest at Choba junction while the lowest was recorded at Lagos Bus Stop as shown below (Figure 8).

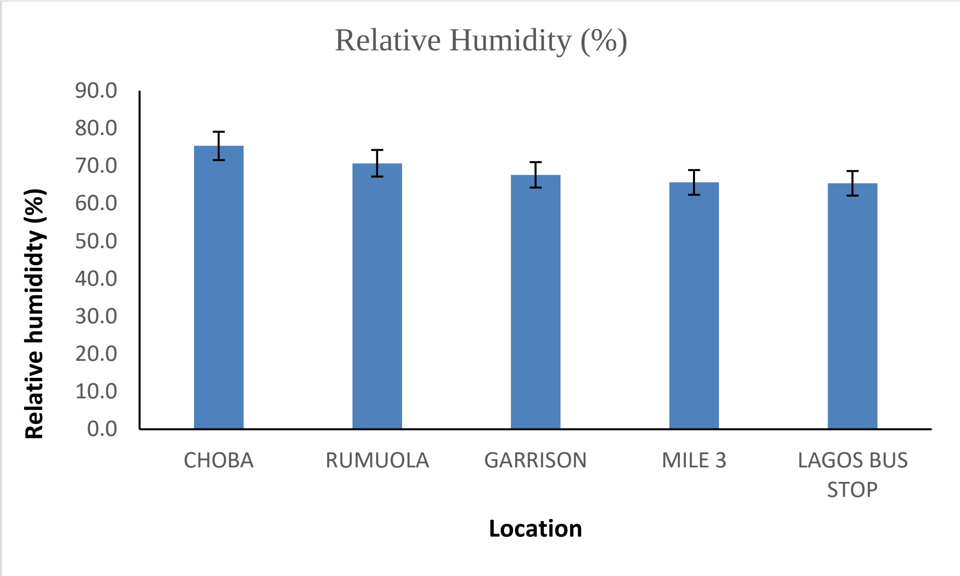

Figure 9: Mean Relative Humidity of Selected Locations at different locations in the Niger Delta, Nigeria.

The analysis of windspeed at selected locations is revealed in Figure 10. The mean windspeed was highest at Mile 3/ UST roundabout while the lowest windspeed was recorded at Choba Junction and Lagos Bus Stop as shown below (Figure 9).

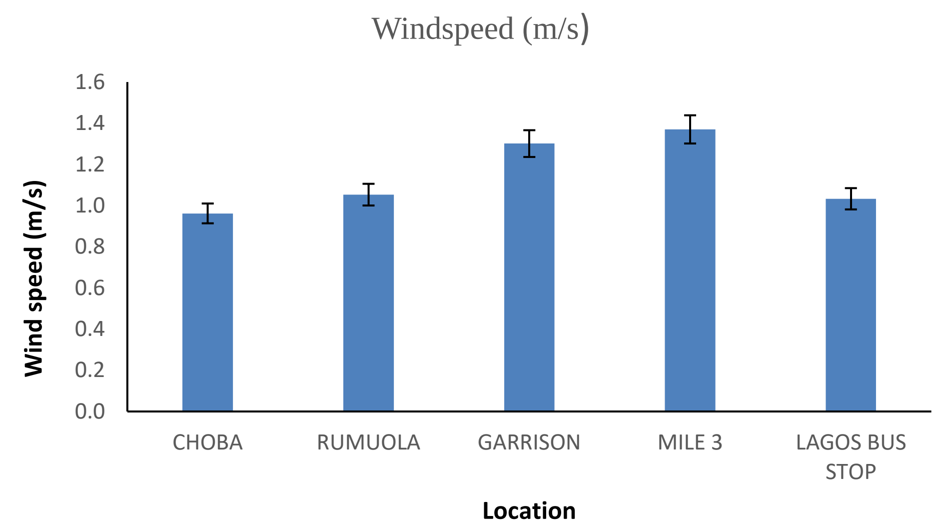

Figure 10: Mean Wind speed of Selected Locations at different locations in the Niger Delta, Nigeria.

Hypotheses Testing: Ho$_1$:
There is no statistically significant variation in concentration levels of carbon monoxide, particulate matter and micro-climatic parameters.

Table 4 below reveals the analysis of variance computed for hypothesis 1. The ANOVA result revealed that there was no significant variation in carbon monoxide, temperature, relative humidity, wind speed, $PM_{2.5}$ and PM_{10} across the selected road junctions in Port Harcourt since the p-value (0.575) was greater than the critical value of α=0.05. The null hypothesis which states that there is no statistically significant variation in concentration levels of carbon exhaust pollutants and particulate matter is therefore upheld. This implies that no statistically significant variation in carbon monoxide, temperature, relative humidity, wind speed and particulate matter exists across the selected road junctions.

Table 4: One-way ANOVA Computed for Hypothesis 1

	Sum of Squares	df	Mean Square	F	P-value.
Between Groups	10.972	7	1.567	.814	.575
Within Groups	6223.551	3234	1.924		
Total	6234.523	3241			

Hypotheses Testing: Ho_2:

There is no statistically significant relationship between micro-climatic parameters and the concentration levels of carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxide (NO_2) and particulate matter at selected road junctions in Port Harcourt. Table 5 below reveals the pearson product moment correlation computed for hypothesis 2. The correlation table revealed that there is no statistically significant relationship between micro-climatic parameters (Temperature, relative humidity, wind speed) and the concentration levels of carbon monoxide (CO), sulphur dioxide (SO_2), and nitrogen oxide (NO_2) as their p-values were greater than the critical value of α=0.05. However, it was revealed that temperature and relative humidity had a statistically significant relationship with the concentrations of $PM_{2.5}$ and PM_{10}. The p-values were less than the critical value of 0.05 which implies a statistically significant relationship of temperature and relative humidity with the concentrations of $PM_{2.5}$ and PM_{10}

Table 5: Pearson Product Moment Correlation Computed for Hypothesis 2

Pollutants	Analysis	Carbon monoxide	Sulphur dioxide	Nitrogen Oxide	Temp.	Relative Humidity	Wind Speed	$PM_{2.5}$	PM_{10}
Carbon monoxide	Pearson Correlation	1	.409	.409	.562	.432	-.169	.663*	.739*
	Sig.(2tailed)		.240	.241	.091	.213	.641	.036	.015
	N	10	10	10	10	10	10	10	10
Sulphur dioxide	Pearson Correlation	.409	1	.733*	.394	.204	-.239	.435	.442
	Sig.(2tailed)	.240		.016	.259	.572	.506	.209	.200
	N	10	10	10	10	10	10	10	10
Nitrogen Oxide	Pearson Correlation	.409	.733*	1	-.623	.468	-.596	.793**	.760*
	Sig.(2tailed)	.241	.016		.054	.172	.069	.006	.011
	N	10	10	10	10	10	10	10	10
Temp	Pearson Correlation	-.562	-.394	-.623	1	-.958**	.380	-.856**	-.891**
	Sig. (2-tailed)	.091	.259	.054		.000	.279	**.002**	**.001**
	N	10	10	10	10	10	10	10	10
Relative Humidity	Pearson Correlation	.432	.204	.468	.958**	1	-.223	.799**	.820**
	Sig. (2-tailed)	.213	.572	.172	.000		.536	**.006**	**.004**
	N	10	10	10	10	10	10	10	10
Wind Speed	Pearson Correlation	-.169	-.239	-.596	.380	-.223	1	-.377	-.380

	Sig. (2-tailed)	.641	.506	.069	.279	.536		.283	.279
	N	10	10	10	10	10	10	10	10
$PM_{2.5}$	Pearson Correlation	.663*	.435	.793**	-.856**	.799**	-.377	1	.988**
	Sig. (2-tailed)	.036	.209	.006	.002	.006	.283		.000
	N	10	10	10	10	10	10	10	10
PM_{10}	Pearson Correlation	.739*	.442	.760*	-.891**	.820**	-.380	.988**	1
	Sig. (2-tailed)	.015	.200	.011	.001	.004	.279	.000	
	N	10	10	10	10	10	10	10	10

*. Correlation is significant at the 0.05 level (2-tailed).

Hypotheses Testing: Ho_3:
There is no statistically significant relationship between concentration levels of carbon monoxide (CO), sulphur dioxide (SO_2), and nitrogen oxide (NO_2) at selected road junctions in Port Harcourt.

DISCUSSION

The study showed variation in the mean concentration levels of carbon monoxide, particulate matter and micro-climatic parameters across the selected study locations. The finding of this study is in line with the findings of Garba Abdulhafiz *et al*. (2020), Iwuala & Oriaku (2019) and Utang & Peterside (2011) who revealed that there were spatio-temporal emissions from road transport that the arithmetic means of the different study location varied slightly. This could be attributed to the characteristics of each junction and the flow of traffic in each study location.

Furthermore, the research also revealed no statistically significant relationship between micro-climatic parameters (Temperature, relative humidity, and wind speed) and the concentration levels of carbon monoxide (CO), sulphur dioxide (SO_2), and nitrogen oxide (NO_2). The finding of this research is in contrast to the findings of Okoroafor & Ikebude (2015) and Chang & Lee (2008) who revealed in their research that there a significant relationship exists between the concentration of atmospheric pollutants and the prevailing meteorological factors.

On the contrary, the study revealed that temperature and relative humidity had a statistically significant relationship with the concentrations of $PM_{2.5}$ and PM_{10}. The finding of this study agrees with the research findings of Giri, et al. (2008), Monn (2001) and Hien et al. (2002) who observed in their separate studies that variations in PM_{10} concentrations should be partially attributable to changes in the meteorological conditions.

The finding of this research revealed that the mean concentration of nitrogen oxide did not exceed the National Ambient Air Quality Standards (NAAQS) stipulated limit of 0.06ppm. However, research finding revealed that the mean concentration of sulphur dioxide exceeded the National Ambient Air Quality Standards (NAAQS) stipulated limit of 0.1ppm in all the selected locations except Lagos bus stop which was below detection limit. In the same vein, the mean concentration of carbon monoxide exceeded the National Ambient Air Quality Standards (NAAQS) stipulated limit of 20ppm in all the selected locations except Garrison bus stop and Lagos bus stop. However, the concentration of particulate matter in all the selected location did not exceed the National Ambient Air Quality Standards (NAAQS) stipulated limit of 250µg/m3. The findings of this research is in agreement to the findings of Asin et al. (2016) and Ojo and

Awokola (2012) whose discovered in their research that the mean concentrations of CO, SO_2 and NO_x pollutants were found to be much higher than the Federal Ministry of Environment limit.

Higher concentration of SO_2 and CO_2 above international standard is because of the industrial nature of Port Harcourt, which has numerous industries that emits gas into the atmosphere. Similarly, there is an influx of pre-owned cars that has poor emission ratings with high level of emission which lead to increase in atmospheric pollutants within and around the city. In the same vein, lack of emission control by the authorities has led to the proliferation of old cars in the city, which results to the emission of large quantities of pollutants into the atmosphere.

CONCLUSION AND RECOMMENDATION

The study was able to establish the spatial variability of carbon emission, particulate matter and prevailing meteorological conditions. The study revealed no significant variation in the concentration of carbon monoxide and particulate matter. Furthermore, the research was able to establish that the correlation between micro-climatic parameters (Temperature, relative humidity, and windspeed) and the concentration levels of carbon monoxide (CO), sulphur dioxide (SO_2), and nitrogen oxide (NO_2) was not significant. However, the study shows that temperature and relative humidity are related with the $PM_{2.5}$ and PM_{10} concentrations. There should be regular monitoring of vehicles through strict emission control to prevent old cars with poor engines from coming into the city. In addition, cars that don't pass emission test should not have their license renewed to prevent increased atmospheric pollution.

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Hydro-priming Effects as A Seed Pretreatment Technique on Early Growth, Development and Yield of *Amaranthus thunbergii* Accessions

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Abstract:
Two field experiments were carried out in Sebele (24o33'S, 25o54'E, 994 m above sea level) during summer 2021/2022. The treatments were two amaranthus accessions collected from South-Eastern region of Botswana as factor A while hydropriming (soaking in preheated water) for duration 0-control (no priming), 30 seconds, 60 seconds, and 90 seconds allocated as factor B. Hydro priming duration and accessions significantly ($P < 0.05$) influenced growth, phenological characteristics and development of amaranthus in both seasons of study. Amaranthus seed accessions and hydropriming significantly ($P < 0.05$) influenced the timing/duration of phenological stages. The time amaranthus seeds took from sowing to seedling emergence hastened with an increase in priming duration. This resulted with an average of 3-6.5 days to emerge from 90 seconds or control as the minimum or maximum days taken to reach emergence, respectively. However, when seeds were exposed to hydropriming for the longest time, days from sowing to branching, flowering and physiological maturity were significantly ($P < 0.05$) delayed. This means 90 seconds duration significantly ($P < 0.05$) resulted with the longest number of days from sowing to branching, flowering and physiological maturity whereas non primed seeds took the shortest time to mature. There were many branches, largest leaf size, highest leaf fresh weight and seed yield when amaranthus seeds were primed for 90 seconds compared to control. In general, hydropriming for 90 seconds duration outperformed all other treatments producing total leaf fresh weight or seed yield of 10306 kgha-1 or 3763 kgha-1, respectively. Comparing accessions, the highest emergence percentage, growth and crop yield significantly ($P < 0.05$) resulted from accession 2 than 1. In conclusion, hydropriming had a significant role in improving phenology, early growth and yield of amaranthus accessions.

Keywords: Amaranthus thurnbegii, hydropriming, seed pretreatment, accessions, leaf yield, seed yield

INTRODUCTION

Amaranthus thunbergii (pigweed) is an indigenous annual herbaceous green leafy vegetable with a dull green ovate leaf from *Amaranthaceae* family (Kolberg, 2001; D'Amico and Schoenlechner, 2017). It contains 70 species varying in use as seed or leafy cultivars (Fatina *et al*., 2013). It is one of the neglected, underutilised crops which were rediscovered due to their health promoting benefits especially in the food industry (D'Amico and Schoenlechner, 2017). The increased intrest in amaranthus was also influenced by the growing awareness of gluten free nutritionin cereals (D'Amico and Schoenlechner, 2017). Amaranthus as a leafy cultivar is native to Sub-Saharan Africa such as Ethiopia, South Africa, Namibia, Botswana (D'Amico and Schoenlechner, 2017;

Jamalluddin *et al.,* 2022), but is also cultivated and consumed as grain or leaves in America, Asia, Europe and Australia (Jamalluddin *et al.,* 2022). The species mostly occur in disturbed soil, cultivated and seasonally wet areas, fields, kraals where manure accumulates (Kolberg, 2001). This species has different morphological characteristics which are affected by plant adaptation and genetic variation (Fatinah *et al.,* 2013). Amaranthus are c4 plants, their carbon fixation pathway makes them well adapted to high light intensities, extreme temperatures and dry conditions hence it is drought and saline tolerant (Zheleznov *et al*., 1997; Jamalluddin *et al.,* 2022). The genus *Amaranthus* is a betaine accumulating genus, a substance that aid in adaptability to saline and dry conditions (Kolberg, 2001). The plant has a wide range of uses by different communities with the most common one being consumption as a green leafy vegetable. During the rainy season, communities will harvest *Amaranthus* leaves and shoots for consumption as a leafy vegetable along with starchy staples (NRC, 1984). This leaves have some health benefits due to high nutritive value such as crude protein (17.92), crude fibre (8.61), ash content (13.80), minerals and vitamins essential for supplementary diets (Obasi and Ugbogu, 2007). The high protein content of *amaranthus spp* has been reported for potential use as protein isolates due to the easy way of extracting a high-quality protein concentrate from the leaves (Kolberg, 2001). Also, amaranthus contains macro components of greater health importance such as squalene, tocopherols, antioxidants, phytates and vitamins (D'Amico and Schoenlechner, 2017). The antinutritional properties contained in the leaves are oxalic and nitrates which are comparable to other commonly consumed leafy vegetables however, they can easily break down or dissolve in boiling water (Kolberg, 2001; NRC, 1984). Also, amaranthus has a betaine content which gives it the ability for use as a plant protectant to resist fungi and root knot nematodes (Kolberg, 2001). Moreover, the leaves have shown potential use as a medicinal plant by the Tswana communities for healing wounds and to stimulate child birth (Kolberg, 2001). The nutritional and therapeutic value of amaranthus leaves indicates its potential to combat malnutrition, boost food security and contribute to income generation in the rural communities.

There is an increased interest of amaranthus products favoured by high degree of adaptability evidenced through genetic and morphological variability, phenotypic plasticity, climate resiliance characteristics, diverse uses and nutritional benefits (Rastogi and Shukla, 2013; Jamalluddin *et al*., 2022). The increase in utilisation resulted in extensive harvesting of the leaves during rainy season for sale by rural communities which can cause exploitation and increase their depletion in native sites (Motlhanka and Makhabu, 2011). However, there is limited information on amaranthus cultivation and propagation techniques (Rastogi and Shukla, 2013). This requires research on finding the effective domestication and cultivation methods to conserve species biodiversity. To ensure sustainability in domestication and commercialisation of indigenous plants, efficient propagation technique is the best approach (Wala and Jasrai, 2003). Studies reports that seed germination and early seedling growth directly determine the crop stand and consequently crop yield hence are marked important (Missanjo *et al*., 2014). Seed germination in most of indigenous crops is sensitive to hydration process and prone to dormancy. Comparing seed pretreatment methods, hydro-priming is the most common, easy technique used to advance germination and growth of several crops (Adinde *et al.,* 2020; Rehman *et al.,* 2014; Farooq *et al.,* 2006). Hydropriming involves pre-soaking seeds to imbibe water as they go through the first stage of germination, yet does not allow radicle appearance, followed by drying to their original weight (Nakao et al., 2018). In this technique, priming duration is determined by controlling the seed imbibition (Kaur *et al*., 2002). Hydropriming helps crops overcome the environmental stress such as drought induced dormancy (Nakao *et al*., 2018). However, in most seeds, hydropriming has a challenge of slow water uptake rate and variability in the time a seed may take to complete the pre-germination process (Adinde *et al*., 2020; Nakao *et al*., 2018). Therefore, finding the effective and efficient hydropriming method or duration for amaranthus accessions will have a direct impact on plant survival, growth, development and genetic improvement (Ngulube *et al*., 1997 and Mng' omba *et al*., 2008). The success of hydropriming technique on *amaranthus spp* may strengthen the indigenous knowledge of green leafy vegetables and ensure efficient utilisation of this species to boost the economy in the rural communities. Domestication of amaranthus species in Botswana can be a mitigation strategy since it is climate smart (Jammalluddin *et al.,* 2022) underutilised indigenous crop with a potential for increasing local food security and improving household diets. Therefore, the objective of the study will be to determine the growth, phenology and development of ***Amaranthus thunbergii*** as influenced by accession and hydropriming duration.

MATERIALS AND METHODS

Experimental Site

Field experiments were conducted in Sebele (24°33'S, 25°54'E, 994 m above sea level) greenhouse.

Treatments and Design

Two factorial experiments were laid under completely randomised design (CRD) with three replications. The treatments were two amaranthus accessions collected from South-Eastern region of Botswana as factor A while soaking in preheated distilled water as a hydropriming method at duration 0 (control-no soaking), 30 seconds, 60 seconds, and 90 seconds allocated as factor B. The plots were concrete benches of dimensions was 3m x 2m where a mixture of vermicompost and sand (1:1) was used as a growing medium.

Cultural and Management Practices

Before planting, amaranthus seeds were immersed in preheated distilled water (80°C) at different time intervals ranging from 0, 30, 60, 90 seconds. After soaking time elapsed primed seeds were dehydrated on a filter paper to their initial weight, thereafter sown directly with 3 seeds placed per seeding point at a spacing of 30cm inter and 30 cm intra row. Regular watering was done as per requirement to maintain adequate moisture. All necessary management practices including water application, fertilizer application, pests, disease and weed control were undertaken to enhance good growth and development.

Data Collection

% Emergence:

This was done by dividing the number of emerged seedlings by the number of planted seeds for each seed lot and multiplying the product by 100.

Plant Height:

During ripening, ten plants were randomly selected in each plot per treatment and measured from the ground level to the leave base of the highest fully expanded leaves using a measuring tape. The average value was used as the average height of the plant.

Leaf Number at Harvest:

During harvesting, the fully matured leaves were counted and recorded as average number of leaves per plot.

Primary Branch Number

The primary branch number was counted and recorded as average number of branches per plot.

Leaf Fresh Weight:

Leaf fresh weight was estimated from the plants growing within a central plot area of 2 m^2.

Seed Yield:

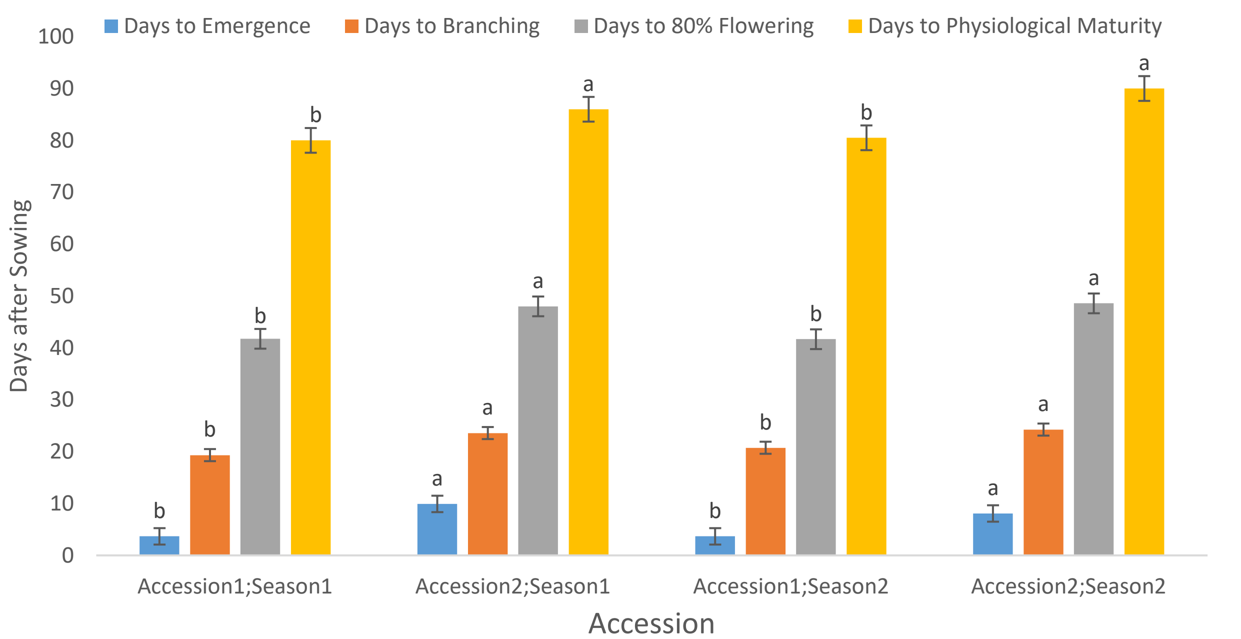
Seed yield was estimated from the plants growing within a central plot area of 2 m^2. The seeds were threshed and winnowed manually from the sample and seed yield per unit area determined. The seeds were weighed using a digital weighing scale (Model 8800-Chicago, USA).

Statistical Analysis

Analysis of variance was performed on the data collected using general linear model (PROC GLM) procedure of Statistical Analysis System (SAS 2009, Carey, NC) program package. Appropriate regression models were used to examine the response of leaves and seeds of bean genotypes to different harvesting times. Multiple comparisons among means was done using Protected Least Significant Difference (LSD) at $p = 0.05$. Proc univariate procedure was carried out on residuals to support assumptions of normality made.

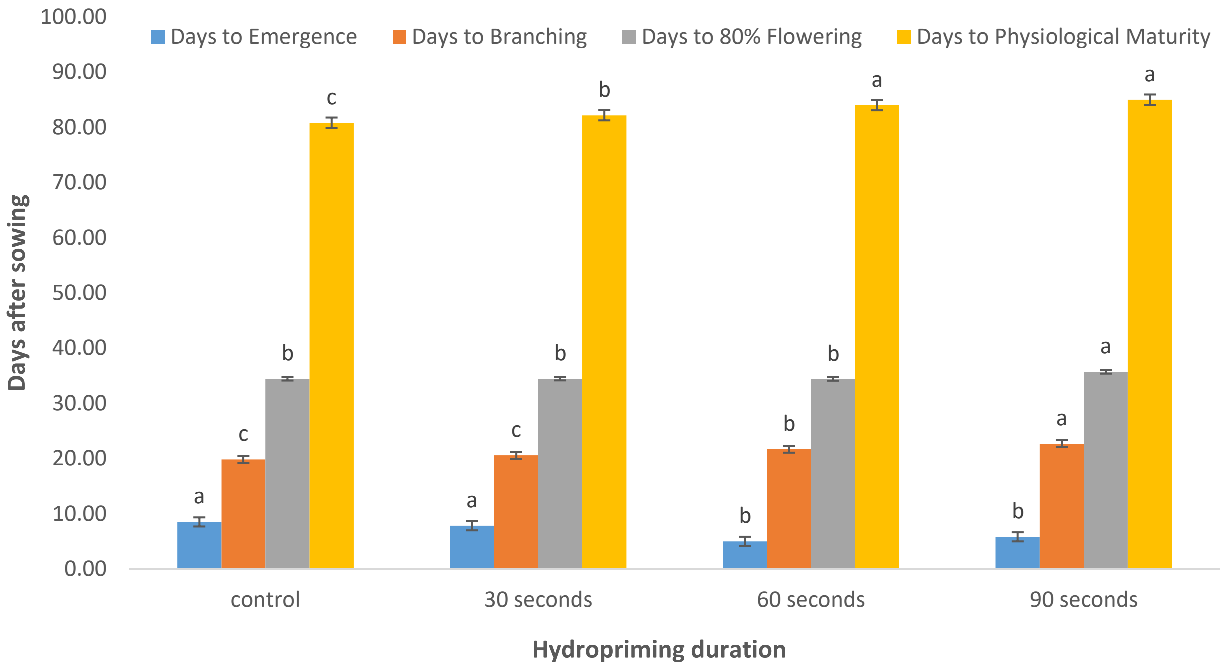
RESULTS

Figure 1: Effect of accession on phenological stages of Amaranthus thurnbegii grown in season 1 and 2



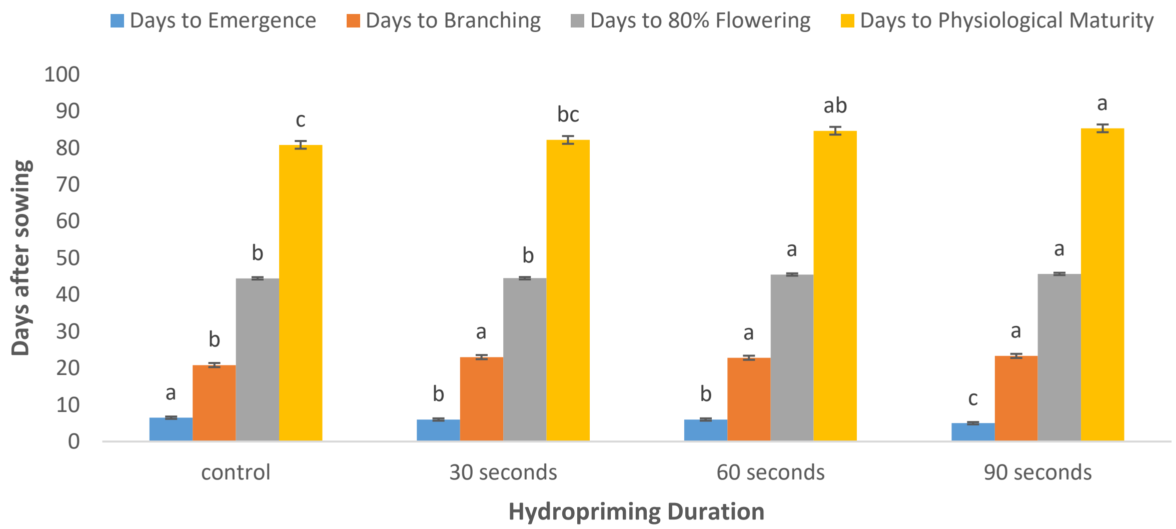
There was a significant (P < 0.05) effect of accession on time amaranthus plants took from days after sowing to reach stages of phenology (Figure 1). Amaranthus seeds took 4-10 days to emerge, with accession 1 taking the shortest time compared to accession 2 (Figure 1). In both seasons plants prolonged from 19-24 days as the minimum and maximum time taken to branching (Figure 1). After branching plants went through flowering process where accession 1 or 2 reached 80% flowering at 32 or 39 days respectively (Figure 1). The grain filling initiation and development stage are the key stages during physiological maturity, they commenced for a minimum and maximum of 80 and 90 days from accession 1 and 2, respectively (Figure 1). This results with 11% significant (P < 0.05) difference among the two accessions studied (Figure 1). The results further shows that there is consistency in response of the two accessions towards the time taken to reach stages of growth among the two seasons of study (Figure 1). The difference in plant response of the two amaranthus accession on timing or duration of phenological stages was influenced by genetic expression among them. Fatina *et al.* (2013) has stated that there is a high genetic variation among the amaranthus species.

Figure 2. Effect of hydropriming on phenological stages of *Amaranthus thunbergii* grown in season 1



Hydropriming duration significantly (P < 0.05) influenced growth of amaranthus from the time seeds took towards emergence, vegetative and reproductive stages (Figure 2). The minimum and maximum time taken by amaranthus seeds to emerge was 5-8.5 days after sowing (DAS) from 90 seconds hyropriming duration (preheating) to control (12hours tap water soaking). This implies that there was a significant (P < 0.05) delay in days to emerge when amaranthus seeds were not primed compared to pre-heating the seeds (Figure 2). Preheating amaranthus seeds for the longest time significantly (P < 0.05) hastened emergence, however there was no significant (P > 0.05) difference between duration 60 and 90 seconds nor for control and 30 seconds duration (Figure 2). The same findings were reported by Farooq *et al* (2011) and Rehman *et al* (2014), in their report earlier emergence was attributed to stimulated starch metabolism which was influenced by an increase in the activity of degrading enzyme such as amylase, synthesis of RNA and DNA, amount of ATP and number of mitochondria, essential elements for germination (Afzal *et al.*, 2002). After emergence plants reached the vegetative stage, hydropriming significantly (P < 0.05) influenced the time plants took from sowing to reach branching stage (Figure 2). Amaranthus plants took an average of 21 days to branching (Figure 2). The longer the seeds were immersed in preheated water the longer they took to commence branch initiation and development (Figure 2). There were a few numbers of days taken from sowing to branching under control compared to other treatments (Figure 2). However, control and 30 seconds priming were not significantly (P > 0.05) different (Figure 2). The reproductive phase commenced with flower initiation and development (Figure 2). Plants significantly (P < 0.05) took a minimum and maximum of 43 and 46 days to reach 80% flowering, from control and when seeds were exposed to priming for 90 seconds, respectively. The response of amaranthus plants towards hydropriming did not significantly (P > 0.05) differ expect for when seeds were treated for 90 seconds (longest time) (Figure 2). Amaranthus plants reached physiological maturity from 80 to 85 days after sowing (Figure 2). There was a significant (P < 0.05) effect in response of amaranthus plants towards the time from sowing to grain filling, initiation, development and maturation process (Figure 2). Hydro priming seeds for 90 seconds significantly (P < 0.05) delayed plants to reach physiological maturity while control exposed seeds took the shortest time from sowing to maturity (Figure 2). Treatments 60 or 90 seconds did not significantly (P > 0.05) differ (Figure 2). Hydropriming provides better utilisation of water, light and nutrients this can lead to an increase in the duration and level of photosynthesis in plants (Finerty *et al*., 1992).

Figure 3. Effect of hydropriming on phenological stages of *Amaranthus thunbergii* grown in season 2



There was a significant (P < 0.05) effect of hydropriming towards growth of amaranthus grown in season 2 (Figure 3). Similar to season 1, Amaranthus plants were significantly (P < 0.05) affected by exposure to hydropriming durations from emergence, branching, flowering to physiological maturity (Figure 3). The seeds significantly (P < 0.05) took 5 to 7 days to emerge as influenced by priming (Figure 3). The shortest and longest time taken from sowing to emergence resulted from 90 seconds priming and 12 hrs of soaking in tap water (control) respectively (Figure 3). Hydropriming duration for 30 or 60 seconds both resulted with 6 days from sowing to emergence hence did not significantly (P > 0.05) differ (Figure 3). Plants significantly (P < 0.05) took 20 to 23 days to branching, with control and 90 seconds priming resulting with the minimum and maximum number of days taken from sowing (Figure 3). All the hydropriming duration taken did not significantly (P > 0.05) differ except for control. Similar to season 1, amaranthus plants significantly (P < 0.05) took 44 to 46 days to reach 80% flowering. Hydropriming seeds for 90 seconds significantly (P < 0.05) delayed flowering by 3% in comparison to control (Figure 3).

Exposure of seeds to 60 or 90 seconds and 30 seconds or control were not significantly (P > 0.05) different (Figure 3). There was a significant (P < 0.05) effect of hydropriming duration in response towards days to reach physiological maturity (Figure 3). Similar to season 1, season 2 grown plants prolonged for a significant (P < 0.05) 80 to 85 days of maturity (Figure 3). The minimum and maximum time taken from sowing to physiological maturity resulted from control and 90 seconds priming, respectively with 5% significant (P < 0.05) difference among treatments (Figure 3). The exposure of amaranthus seeds for 60 or 90 seconds, 30 or 60 seconds and control or 30 seconds were not significantly (P < 0.05) different (Figure 3).

In general, the season1 and 2 results has revealed a consistent pattern in plant response to hydropriming duration across all stages of growth except for days to emergence irrespective of season (Figure 2). That is, when amaranthus seeds are exposed to priming for the longest time, duration from sowing to branching, flowering and physiological maturity may be significantly (P < 0.05) delayed (Figure 2). Whereas soaking in tap water or seed priming for the shortest time significantly (P < 0.05) hastens growth (Figure 2).

Table 1: Effect of accession and seed pre-treatment methods on growth and yield of *Amaranthus thunbergii*

Accessions	% Emergence	Height at ripening	Leaf number	Leaf Area	Primary branch number	Leaf yield	Seed yield
Season 1							
Accession 1	98.33a	50.48b	25.98a	2.75b	6.5b	3050 b	2475.6b
Accession 2	62.50b	60.42a	10.19b	40.73a	11.58a	14863.9 a	3528.2a
LSD	10.74	2.67	3.68	3.68	1.011	810.8	543.6
Significance	****	****	****	****	****	****	***
Season 2							
Accession 1	98.33a	50.81b	25.53a	2.73b	6.83b	3032.2b	2555.2b
Accession 2	67.50b	61.15a	10.33b	40.71a	11.58a	14500a	3511.7a
LSD	9.42	2.81	2.41	3.57	1.62	843.7	519.2
Significance	****	****	****	****	****	****	***

Genotype and hydropriming duration had a significant (P <0.05) effect on growth and development of amaranthus in the two seasons of study, however their interaction was not significant (Table 1). The highest emergence speed and percentage resulted from genotype 1 than genotype 2 across seasons (Table1), thus genotype 1 had 98% emergence compared to genotype 2 which was 53-57% in both seasons. The number of primary branches for genotype 2 were significantly (P < 0.05) 42% higher than that of accession 1 (Table 1). During ripening, amaranthus accession 2 plants were significantly (P < 0.05) taller than accession 1 plants (Table 1). There was a significant (P < 0.05) effect of genotype towards influencing the leaf growth of amaranthus (Table 1). The leaf size for Accession 1 plants were smaller with an area of 3 cm^2 and yet produced many leaves (26 leaves) compared to accession 2 which had a larger surface area of 41 cm^2 but fewer leaves (10 leaves) (Table 1). The leaf area versus number compensation reveals a leaf size versus number trade off theory which is observed and reported in most plants (Kleiman and Aarssen, 2007). Amaranthus leaves were harvested fortnight and the leaf fresh weight or yield accumulated (Table 1). There was a significant difference (P < 0.05) in leaf fresh weight of amaranthus as affected by accession. The highest leaf yield was 14 864 kg ha^{-1} from accession 2, while the lowest yield was 3032 kg ha $^{-1}$ from accession 1 (Table 1). This resulted with 79% accession difference across seasons of study (Table 1). The small leaves are reported to have a positive association with reduced leaf area duration (Moles and Westoby, 2000). This means the leaf area of accession 1 may be influenced by a shorter leaf area duration which restrict the assimilate synthesis. The highest leaf fresh weight produced by accession 2 is attributed to a larger leaf area which strengthen the source-sink related activities, this difference in leaf yield is influenced by genetic expression. The leaf size has a direct adaptive significance, Gonzalez et al. (2010) reported that the genes that increase leaf size ultimately influences increase in crop yield hence designated as intrinsic yield genes. This means the leaf of a plant should be large enough to absorb sufficient sunlight for photosynthetically active radiation (PAR). Even though accession 2 had a few number of leaves, it was compensated by the size as it was reported to have largest leaf area. The longest time taken by primed seeds enhanced an increase in cell division which when coupled with an improved water and nutrient absorption can improve crop establishment hence more cell division and expansion contributing to a larger leaf area. During physiological maturity, amaranthus seeds were dried and harvested resulting with significantly ($P < 0.05$) the lowest and highest seed yield of 2555 and 3528 kg ha^{-1} produced by accession 2 and 1 from season 1 respectively which is 30% difference between genotypes (Table 1). This was attributed to the number of leaves as accession 1 had many leaves in number compared to accession 2. Leaf growth in terms of size, number and positioning within the plant are the key contributing factors towards photosynthesis and its related activities such as accumulation and translocation of assimilates to the sink area for grain filling and production all of which play a key effect in overall seed yield. The lowest seed yield produced from accession 2 is influenced by lowest leaf growth (leaf area/yield). Growth and reproduction is obtained from meristematic tissues, more leaves produced by a crop means more meristems/bud per shoot are required to provide for greater phenotypic plasticity in adjusting allocation of meristems/buds to vegetative than reproductive functions (Bonser and Aarssen, 1996).

Table 2: Effect of seed pre-treatment methods on growth and yield of *Amaranthus thunbergii*

Seed Preheating Duration	% Emergence	Height	Leaf number	Leaf Area	Primary Branch number	Leaf yield	Seed yield
Season 1							
Control	54.00c	55.60ab	17.32b	17.45b	8.5bc	8238.9b	2528.4b
30 seconds	72.33b	53.10b	13.37c	17.16b	7.83c	8644.4b	2311.3b
60 seconds	72.33b	58.45a	17.88ab	24.03a	9.83ab	8638.9b	3438.7a
90 seconds	90.00a	55.63ab	20.78a	23.31a	10.00a	10305.5a	3729a
LSD	16.33	4.06	3.45	5.59	1.54	1233	826.5
Significance	*	ns	*	*	*	**	**
Season 2							
Control	60.33c	56.20ab	17.30b	19.09bc	8.83a	7828.9b	2563.4b
30 seconds	75.00ab	53.52b	17.22b	21.02ab	8.00a	8467.8b	2316.8b
60 seconds	80.00a	58.61a	16.42b	23.59a	10.00a	8756.1b	3490.4a
90 seconds	88.33a	55.58ab	21.00a	24.66a	10.00a	10011.7a	3763.4a
LSD	14.32	4.27	3.66	5.42	2.46	1283	789.4
Significance	*	ns	*	*	ns	**	**

Emergence percentage of *Amaranthus* was significantly (P < 0.05) affected by hydropriming duration resulting with the lowest and highest response at control and 90 seconds respectively in season 1 and 2 (Table 2). The efficiency of seed hydropriming for better seedling emergence is reported by Rinku *et al.*, (2017); Damalas *et al.*, (2019); Adinde *et al.*, (2020) and Debta *et al.*, (2023). Also, Elias and Soltani (2015) reported that priming influences the emergence speed and rate, while Ibrahim *et al.*, studied rice and found an earlier and improved germination with increased time to hydroprimed seeds and attributed it to increased moisture imbibition during priming. Abbasdokht *et al.* (1990) also found similar results with maize and confirmed that there is early and uniform germination in primed compared to unprimed seeds. There were significantly (P < 0.05) more number of leaves (21) when seeds were soaked for 90 seconds compared to other time intervals. The number of leaves from any other priming duration except 90 seconds did not significantly (P > 0.05) differ (Table 2). Leaf area of amaranthus plants ranged between 17-24 cm^2, with the lowest and highest area resulting from control and seeds soaked for 90 seconds respectively across seasons (Table 2). However, seeds soaked for 60 or 90 seconds and those from the control and 30 seconds did not significantly differ, respectively (Table 2). There were significantly (P < 0.05) more number of primary branches when seeds were hydroprimed for the longest time during season 1(Table 2). This resulted with control and 90 seconds producing the lowest and highest number of branches, respectively (Table 2). The findings are in agreement with those of Matsushima and Sakagami (2013) who reported an improved shoot growth in primed compared to non-primed seeds. Zarei *et al*. (2011) reported the same findings when studying chickpea. In their findings the increase in number of primary branches by hydropriming was due to essential environmental resources available such as an earlier and increased water or nutrient absorption by vigourous root system (Zarei *et al.,* 2011; Reehman *et al.,* 2014). The improved crop vigour and/or growth was suggested tobe influenced by stimulated starch metabolism (Farooq *et al.*, 2011). Furthermore, the reduced number of branches from shortest priming durations including control may be due to hastened growth which contributed to a few number of days (20-21 days) taken from sowing to branching. The accelerated growth or development from plants which delayed in emergence may be due to an increase in temperature during vegetative growth, resulting in reduction of vegetative growth which finally decreased the number of branches per plant (Zarei *et al.,* 2011). The lowest and highest leaf yield or fresh weight was produced from control and 90 seconds seed pretreatment (Table 2). Thus, when seeds were soaked for 90 seconds they yielded a range between 10012 to 10300 $kgha^{-1}$ respectively (Table 2). However, all pretreatment methods were not significantly (P > 005) different expect 90 seconds (Table 2). Amaranthus planted in season 1 produced seeds of range between 2311-3729 $kgha^{-1}$ from soaking seeds from 0-90 seconds as the lowest and highest performing treatments, respectively (Table 2). A similar response was experienced in season 2 (Table 2). For both seasons seed pretreatment duration of 0-30 or 60-90 did not significantly (P > 0.05) differ (Table 2). The increased yields were also reported by Kaur *et al.* (2005) and Clark *et al.* (2001) who found similar results and reported 11 and 14% increase in chickpea and corn, respectively. Increased leaf and seed yield at 90 seconds priming were attributed to accelerated or improved emergence, increase in yield related components such as branch number, leaf area and number, leaf fresh weight and delayed phenology. This means that physiological activities commence early and the longest time the plant takes in a stage of phenology permits the plant to accumulate sufficient photo assimilates essential for leaf and grain yield. The increase in seed/grain yield could also be influenced by high leaf area, which promotes sufficient leaf capture of photosynthetically active radiation for accumulation of assimilates and efficient utilisation on grain filling process. An improved leaf vigour may influence a high net assimilation rate and crop growth rate essential for photosynthetic activities (Rehman *et al.,* 2014). These findings were confirmed by Rehman *et al.*

(2014) who found a positive correlation between linola seed yield and days to maturity. Farahaminand (2011) and Yari *et al.,* (2011) findings were in agreement with those of the current study while researching on upland rice and basil seeds. Hydropriming has been reported to increase the α-amylase activity which correlates with seed sugar content and seedling dry weight (Nakao *et al.,* 2018). This implies that from the current study the longest time (90 seconds) taken during hydropriming influenced an increased enzymatic activity to hydrolyse more starch and produce more soluble sugar essential for germination, early crop growth and development compared to control (no priming). This improved emergence percentage and time, prolonged crop maturation, increased growth (plant height, leaf area, leaf fresh weight) and produced high seed yield.

CONCLUSION

Hydropriming indigenous seeds of amaranthus by soaking in preheated distilled water for 90 seconds followed by drying to their initial weight improved emergence percentage, phenology, early seedling growth and yield. Accession 2 was the best performing in terms of growth, development and yield. Therefore, for domestication of indigenous amaranthus species in Botswana, hydropriming is recommended to enhance seedling emergence and produce high quality seedlings.

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