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Original article

Effects of different growth media on water quality and plant yield in a catfish-pumpkin aquaponics system

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ABSTRACT

Aquaponics production of fish and plant is one of the environmentally sustainable farming methods of the twenty-first century. In this study, two agricultural wastes (Palm kernel shells aka PKS and Periwinkle shells aka PWS) were evaluated for their suitability as growth beds in the propagation of pumpkin *Telfairia occidentalis.* In addition, conventionally used gravel and its mixture with PKS and PWS (33.33% each) were also tested. The resultant effects of these treatments on water quality of the system were reported. The result obtained reveals better performance of pumpkin in the PKS and PWS medias in terms of vine length, leave area, leave number, branch number and bi-weekly plant yield. The least performance was observed in the plants propagated in the gravel substrate. Water quality and percentage nitrogenous compound reduction (NH_3, NO_2 and NO_3) across the system and in the different grow beds suggests that mixing all substrate resulted in better water qualities for fish and plant growth. Aside the superior growth observed in this study, alternative uses of these agricultural by-products in aquaponics system is highly recommended because of the possibility of converting waste to wealth.

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1. Introduction

Aquaponics combines re-circulatory aquaculture system with hydroponics system in an integrated symbiotic farming concept that ensures efficient nutrient recycling. In this system, the excretory products of the fish are broken down by microorganisms and the resultant by-products inputted into the hydroponic system for plant growth (Bosma et al., 2017). As the plant utilises these metabolites, it purifies the water which in turn is reused in the aquaculture system for fish production (Chaves et al., 1999). Hence, this allows the sustainable growth of the crop without the use of chemical fertilizer and the fish with lowered water budget. The concept of aquaponics system takes root from the ancient practice of integrated fish farming such as the rice-cum fish and the poultry-cum fish culture (FAO, 2001). The suitability of the aquaponics system in areas with limited land and water resources cannot be over emphasised. This is because it is capable of producing up to three and six times the quantity of plants output of a conventional planting system (Resh, 2004) and utilise less amount of freshwater needed to produce fish in a conventional aquaculture system (Liang and Chien, 2015). Consequently, this system is perceived to be a possible sustainable solution to the inadequacies of fish and crop production as well as unemployment and trade deficit (due to high importation of food products) in many underdeveloped and developing countries (Bosma et al., 2017).

In aquaponics system, three types of beds are widely used namely: Nutrient film technique (NFT), ebb-and-flow (EAF) and the deep water culture (DWC) also known as the RAFT beds (Delaide et al., 2017). Most EAF beds are composed of heavy substrate such as clay balls, gravels, sand, perlite, etc. These serve as support systems for the plants and as bioremediation medias (Rakocy and Hargreaves, 1993). Some researchers have evaluated the suitability of other media types to support plant growth. These include Sphagnum peat moss and coconut fiber (Yaghi and Hartikainen, 2013; Bhatnagar et al., 2010; Boxman et al., 2017). However, there are still numerous materials generally considered as waste which could function in place of conventionally used growth medias; consequently, converting waste to wealth. Among such materials is the Palm kernel shells (PKS) and the Periwinkle shells (PWS). These are inedible by-products originating from

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agriculture and aquaculture industries and are usually burnt to supply energy or dumped in piles to decompose. Stock piling of these by-products in landfills or open dumpsites causes environmental problems such as contamination and pollution (Mo et al., 2016). One of the possible solutions to these problems would be finding alternative uses for the by-products as a form of waste management, hence one of the aims of the present study.

Fluted Pumpkin (*Telfairia occidentalis*) is a tropical vine propagated in West Africa mainly for its leafy vegetables and edible seeds (Idris, 2011). It is a member of the family Cucurbitaceae and indigenous to south eastern Nigerian (Akoroda, 1990). Besides its primary use in preparing different types of soup, this plant has found its pride of place in herbal medicines (Nwanna, 2008). This is because the leaves contain high amount of antioxidants, hepato-protective and antimicrobial properties (Nwanna, 2008). Although the fruits are inedible, the seeds contain about 53% fats and 27% crude proteins, hence; it is generally regarded as an oil seed (Okoli and Mgbeogu, 1983). However, to the knowledge of the researchers, no study has attempted to raise *Telfairia occidentalis* in an aquaponics system. Hence, this research was designed to evaluate the suitability of different growth medias in the production of this very important vegetable, using a small-scale aquaponics system. The resultant effects on the water quality of the system were also investigated and reported.

2. Materials and method

This study was conducted at the Agricultural Department of the National Biotechnology Development Agency (NABDA) Head quarter. It is located along the Umar Musa Yar'adua Express, Airport road Lugbe Abuja, Nigeria. A pictorial model of the small-scale aquaponics system used for the study is as presented in Fig. 1 and Table 1 (showing layout and dimensions of the facility respectively). The Palm Kernel Shell (PKS) for this study were obtained from the Palm Oil milling industry located in Imo State Nigeria; while the Periwinkle shell (PWS) were sourced from local fish waste dumping site located at Ogoja area of Cross River State Nigeria. Both by-products were separately sorted to eliminate debris and autoclaved at 100 °C for 1 h to reduce microbial load of these materials. Thereafter, they were rinsed in clean water and sundried (12 h) before placing each in planting troughs of the aquaponics system (filled to 50% capacity). Two additional growth medias namely; Gravel (GRV) (considered as the control growth media) and a mixture of all three growth beds (i.e. PKS, PWS and GRV at 33.33% each) were investigated alongside. The final setup for this study had eight planting troughs for each growth medium (i.e. 8 troughs × 4 treatments).

Table 1
System dimension of the aquaponics system.

S/N	Tanks	Dimensions
1	Fish rearing tanks	200 L
2	Planting bowls	0.045 m^3
3	Mechanical filter tank	20 L
4	Sump tank	250 L
5	Hydraulic loading rate	7.5 L/hr
6	Water volume in system	800 L (0.8 m^3)
7	RAS land area occupied:	12 m^2
8	Hydroponic land area occupied	48 m^2

Pumpkin pods for this study were purchased alongside the PKS from Imo state Nigeria. The pods were cut to expose the seeds and two seeds were planted in each trough. Two hundred juveniles of African Catfish *Clarias gariepinus* (weight = 9.97 ± 0.21 g; length = 12.07 ± 1.92 cm) were obtained from the NABDA Aquaculture production Laboratory and reared in the aquaponics system. Hence, the four fish holding tanks connected to the aquaponics system in this study had 50 fish each.

During the four months of this study, the fish were fed popular commercial diet Coppens® (45% CP, 1.5% fiber, 8.2% moisture, 9.5% ash) at 5% of the total weight. The final weight and other calculated indices of growth were done as adopted by Okomoda et al. (2017). Water quality parameters such as temperature, pH, dissolved oxygen (DO), Alkalinity, hardness, ammonia (NH_3), nitrite-nitrogen (NO_2) and nitrate-nitrogen (NO_3) were monitored weekly in the system using a digital multi-parameter water checker (Hanna water tester Model HL 98126). Water samples for these were

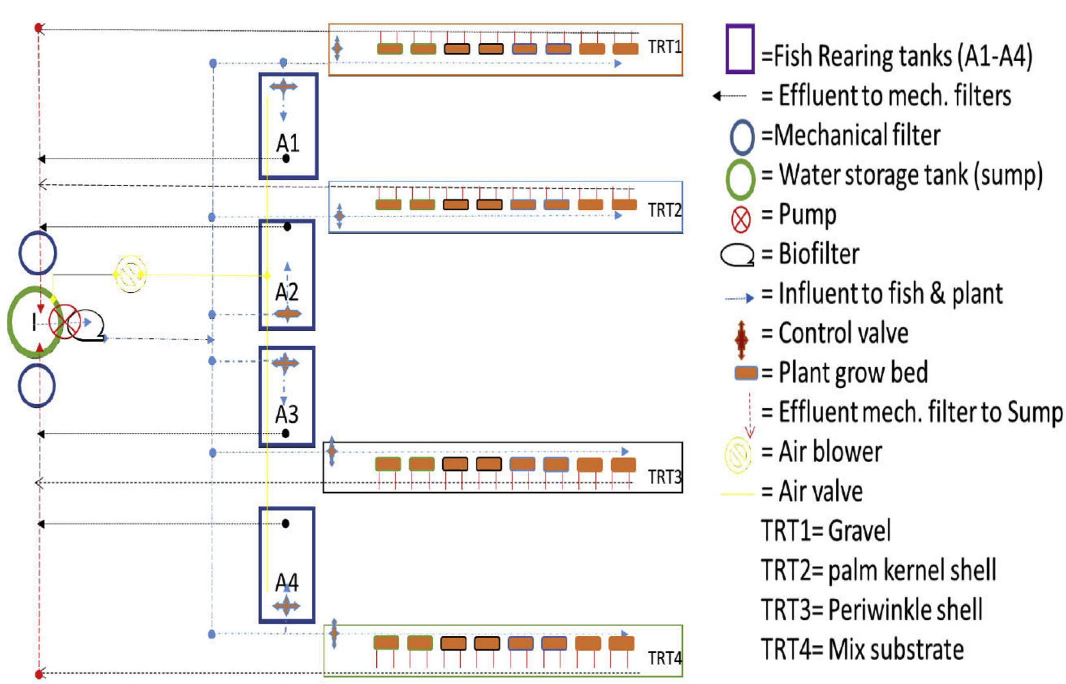

Fig. 1. Aquaponics system layout as designed and constructed for the study.

collected from the fish tank and from the inlet as well as outlet of each growth bed across the system. The percentage of NH_3, NO_2 and NO_3 removal as the waste water passes through the different growth media was also computed using the formula proposed by Effendi et al. (2015) as follows:

$$\%\ \text{Reduction} = \frac{a - b}{a} \times 100$$

where

a = concentration in the inlet water
b = concentration in the outlet water.

Data collection for the yield parameters of the plants were initiated four weeks after seed germination and subsequently every two weeks according to the method specified by Cornelissen, et al. (2003). This includes the vine length, leave number, number of branches and plant yield. Descriptive statistics of all data collected were analysed using mini tab 14 computer software followed by one-way analysis of variance (ANOVA). When significant ($P < 0.05$) differences were observed, data were separated using Fisher's least significant difference.

The basic assumption upon which this study was conducted was that the number of fish reared and vegetable seedling propagated matches between nutrient input and requirements. It was also hypothesised that a hydraulics loading rate 7.5 L/hr was sufficient for the hydroponics system of this setup. Lastly, it was assumed that daily addition of 5% of the total water in the aquaponics system was adequate to compensate for evaporation and transpiration losses as proposed by Maucieri et al. (2017).

3. Result and discussion

All the physico-chemical parameters in the fish rearing tanks (Table 2) were within the recommended range for aquaculture as stated by Boyd (1982) and Ajani et al. (2011). Although the temperatures recorded in this study was higher and the pH lower than trade-off value proposed by Tyson et al. (2008) for plant, fish and nitrifying bacteria in an aquaponics system, it seem not to have detrimental effect on the culture species of this study. In fact, the fish reared in the aquaponics system gained 655.89 ± 0.98 g within the four months of culture from an initial weight of 9.97 ± 0.55 g. Hence, since a sustained growth was achieved and no nutrient deficiency or disease was visually observed in the plants and catfish respectively, it could be said that these conditions are within tolerable limits for catfish-pumpkin aquaponics system. However, the differences in the findings of these two reports could be a pointer to species specific requirements of different plant and fish combination in an aquaponics system.

The choice of PKS and PWS is somewhat unorthodox in an aquaponics system as most media base systems utilise sand, gravel, perlite, or expanded clay pebbles as growth media (as stated by Rakocy and Hargreaves, 1993). Most of the value for water quality recorded were similar (with no significant difference), except for NH_3, NO_2 and NO_3 ($P \geq 0.05$) when water from the different parts of the system were compared (Table 2). Maucieri et al. (2017) had similarly observed insignificant differences in the value of all but one water qualities (ie. NH_4) in different part of their aquaponics system. Taking cognisance of the nutrient mass balances in an aquaponics system is important in identifying

Table 2
Water Quality Parameters from fish effluents and across the different media.

	Fish effluent	Water inlet	Water outlet			
			GRV	PKS	PWS	MIXED
Temperature (°C)	27.83 ± 0.20	28.90 ± 1.50	28.79 ± 1.50	28.61 ± 1.2	28.69 ± 1.50	28.35 ± 1.90
pH	6.80 ± 0.01	6.85 ± 0.10	6.82 ± 0.51	6.85 ± 0.50	6.94 ± 0.51	6.92 ± 0.30
DO (ppm)	6.68 ± 0.03^{a}	4.41 ± 0.60^{b}	4.39 ± 0.49^{b}	4.18 ± 0.50^{b}	4.38 ± 0.45^{b}	4.65 ± 0.32^{b}
NH_3 (ppm)	8.81 ± 0.11^{a}	6.80 ± 0.60^{a}	2.30 ± 0.80^{b}	1.40 ± 0.50^{b}	1.53 ± 0.33^{b}	0.82 ± 0.09^{b}
NO_2 (mg^{-1})	0.31 ± 0.35^{d}	0.66 ± 0.06^{a}	0.52 ± 0.04^{c}	0.54 ± 0.03^{bc}	0.59 ± 0.04^{b}	0.58 ± 0.04^{b}
NO_3 (ppm)	53.18 ± 2.40^{d}	122.3 ± 9.30^{a}	104.2 ± 5.20^{b}	78.90 ± 2.58^{c}	80.31 ± 3.24^{c}	71.5 ± 4.72^{c}
Alkalinity (ppm)	66.23 ± 0.47	66.14 ± 17.9	66.32 ± 18.0	66.11 ± 17.9	66.53 ± 18.0	66.20 ± 17.9
Hardiness (ppm)	84.9 ± 0.66	84.2 ± 1.30	84.2 ± 1.30	84.01 ± 1.30	84.50 ± 1.40	84.03 ± 1.30

Mean in the same row with different superscripts differ significantly ($P < 0.0$).

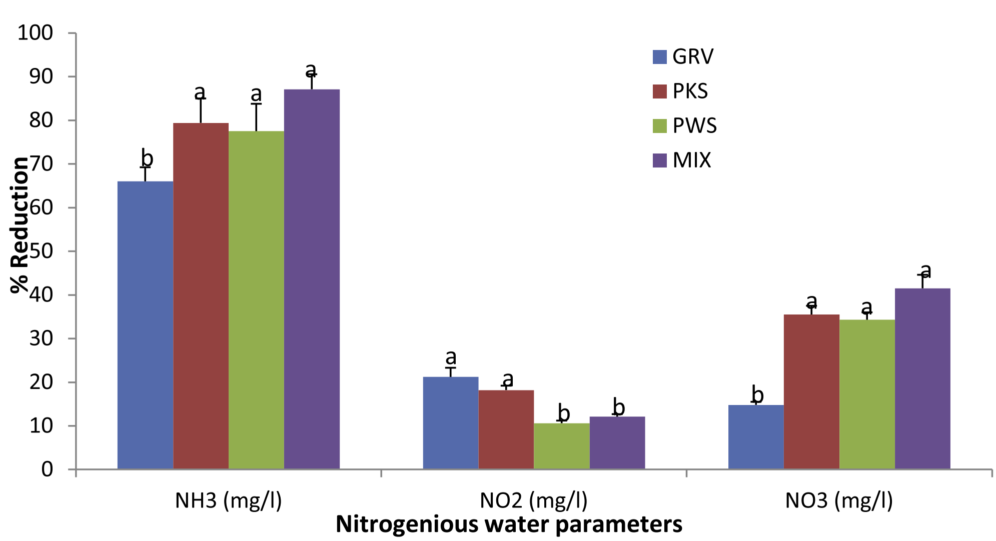

Fig. 2. Reduction of Nitrogen compound in aquaponics system from the different substrates. Data shown are Mean ± SE. Bars with different letters are significantly different from each other ($P \leq 0.05$).

precisely where the nutrients are trapped and which proportion was recycled or lost (Delaide et al., 2017). The value of the nitrogenous water qualities in the system were in the following order; fish tank > trough inlets > trough outlets and were thought to be an indication of the actions of the nitrobacteria present in the system. Schmautz et al. (2017) and Bittsanszky et al. (2016) had earlier opined that microbial communities play an important role in the nutrient dynamic of aquaponics systems by converting ammonium to nitrate, hence facilitating the processing of particulate matter as well as dissolved waste. It is important to note that the uptake of nitrogen as well as phosphorus by plant is only a fraction of the amount generally removed from the water; hence, this indicates that microbial processes in the root zone as well as the substrate in which the plant was propagated play a major role here (Trang and Brix, 2014). However, the finding of this study is in consonant with the reports of Tyson et al. (2004), Graber and Junge (2009) and Maucieri et al. (2017) who observed significantly lower values of NH_4 in the hydroponic tank and biofilter components of their system when compared to the values recorded in the fish tank. On a general note, the low levels of ammonia and NO_2 observed in this study could be an indication of a well-developed microbial community in the different media. This is similar to the findings of Fang et al. (2017) using media based aquaponics system with different aeration levels. The above-mentioned result also compares favourably with the study reported by Wahyuningsih et al. (2015) while using lettuce in an aquaponics system. Akinwole and Dauda (2014) had also shown that Palm kernel shell resulted in better nitrification efficiency compared with imported polypropylene blocks used for the treatment of aquaculture waste water. This is similar to the findings of this study. Worthy of note is the fact that the percentage reduction in ammonia value in this study was far greater than the percentage observed for nitrite and nitrate in all the treatments (Fig. 2). This could be explained by the hypothesis made by Yamamoto et al. (2008) that the proliferation of ammonia oxidizing bacteria, are much faster than that of the nitrite oxidizing bacteria. However, despite the fact that

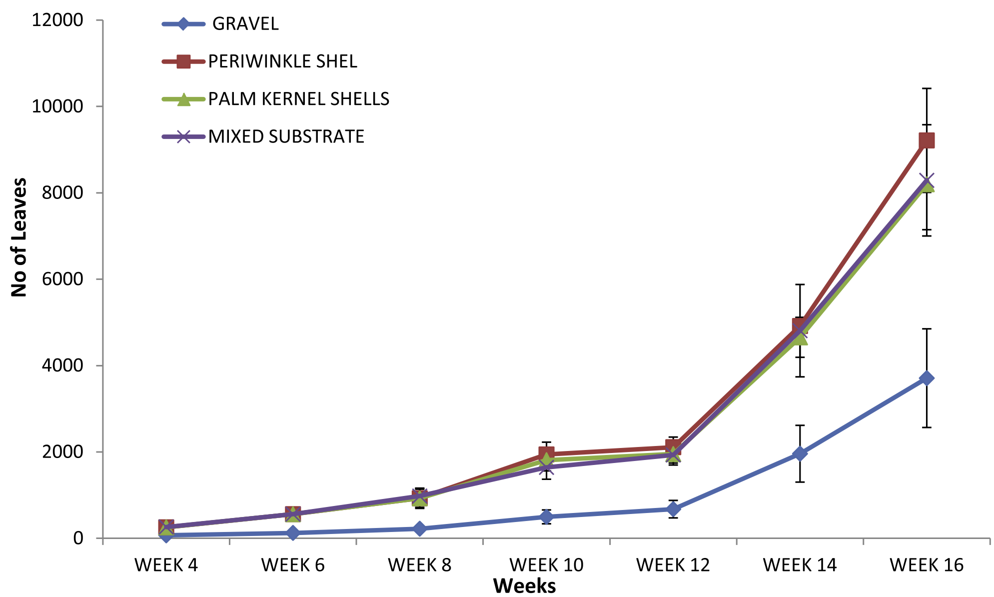

Fig. 3. Leave numbers of Pumpkin propagated in different substrates of an aquaponics system. Data shown are Mean ± SE.

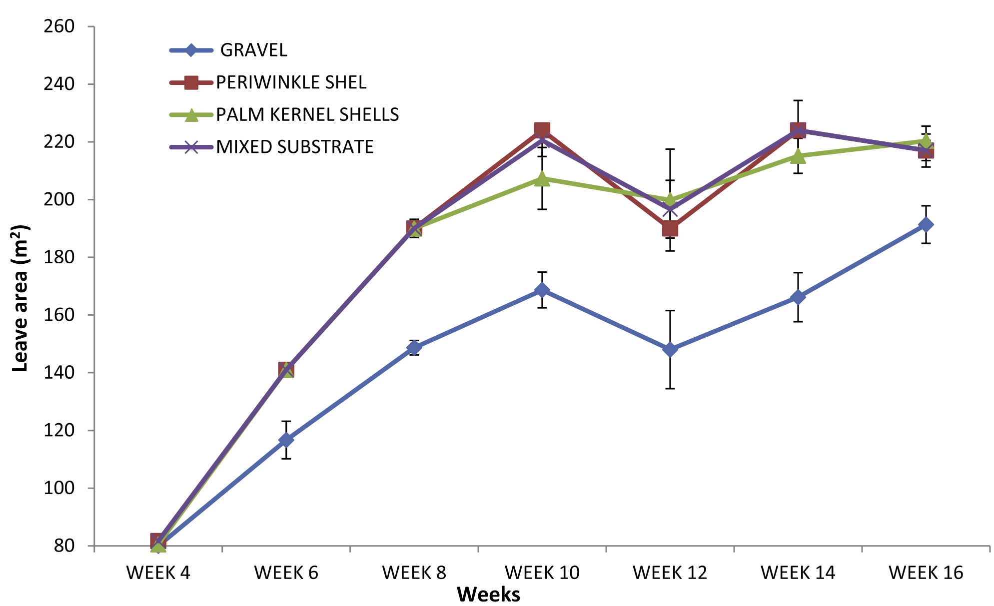

Fig. 4. Leave area of Pumpkin propagated in different substrates of an aquaponics system. Data shown are Mean ± SE.

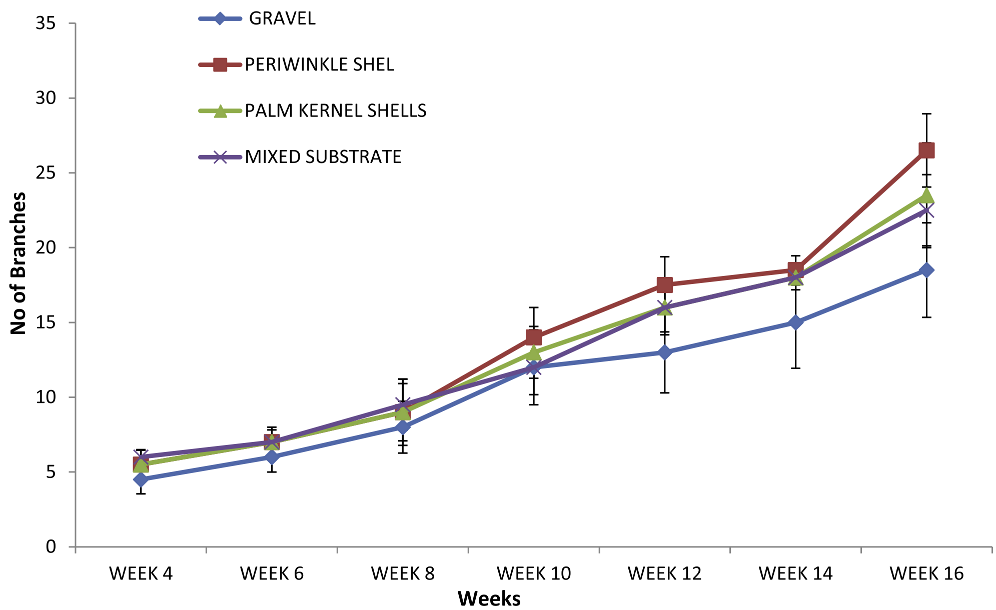

Fig. 5. Number of branches of Pumpkim propagated in different substrates of an aquaponics system. Data shown are Mean ± SE.

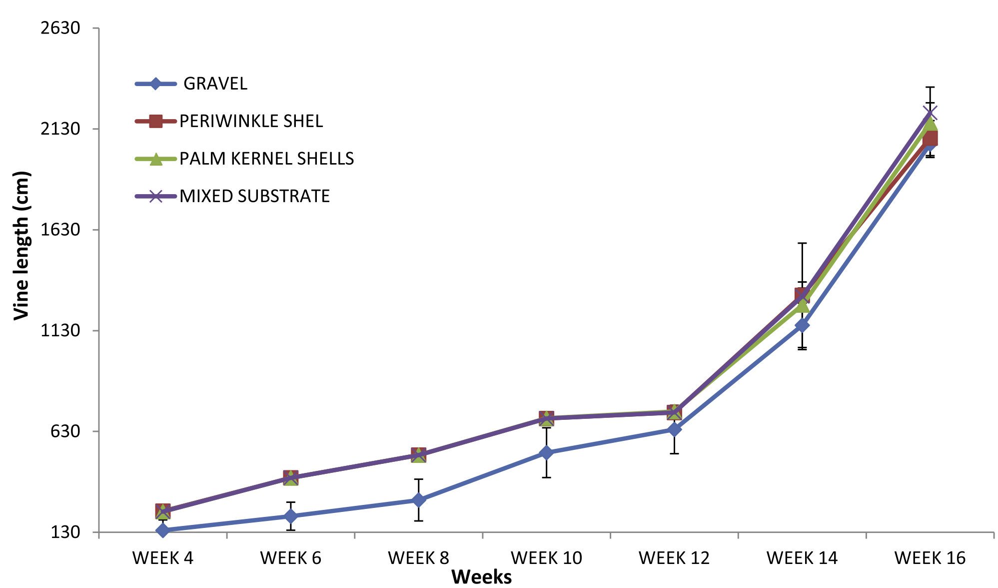

Fig. 6. Pumpkin vine length in different substrates of an aquaponics system. Data shown are Mean ± SE.

plants use up nitrate much faster than ammonia (Britto et al., 2002) more of the former were observed in the system than the latter. This may be because of the low plant to fish ratio in this study.

According to Bosma et al. (2017), the choice of a vegetable for an aquaponics system is based on three parameters namely; the market demand, the convenience for growing fish and vegetables in an aquaponics system, and the match between nutrient input and requirements. Hence, only a few plants have been successfully grown in aquaponics systems and includes lettuce, cucumbers, bell peppers, tomatoes, eggplant (with some extra care) and root crop such as carrot (Graber and Junge, 2009; Kamal, 2006; Sajjadinia et al., 2010; Roosta, 2014). Generally, the market demand of pumpkin is very high, hence fulfilling Bosma's et al. (2017) first condition. The successful propagation of pumpkin as reported in this study is in fulfilment of the second condition while the last condition was logically assumed appropriate however; this could be the focus of future researches. Aside factors such as air, water, temperature and light, the production and harvestable biomass of crops in an aquaponics system is significantly linked to nutrient availability and possibility and ease of uptake (Roosta and Hamidpour, 2011; Liang and Chien, 2015). The findings of the studies by Trang et al. (2010), Lennard and Leonard (2006), suggest that different growth media could affect the nutrient uptake of plants in an aquaponics system. Consequently, this could diminish or increase the growth efficiencies of the crop. However, the finding of this study suggest that the performance of Pumpkin was by far better using the unconventional growth medias compared to the Gravel (Figs. 3, 4, 5, 6 and 7) or the mixed medias. This may be connected to the differences in the level of nitrification occurring in the different media. It is therefore hypothesised that the different levels of nitrogenous waste in the different media affected the plant utilization and uptake of nutrient and consequently the yield. Sikawa and Yakupitiyage (2010) had earlier opined that a good medium for plant growth in an aquaponics system should create a nutrient pool as well as provide adequate air space for respiration around

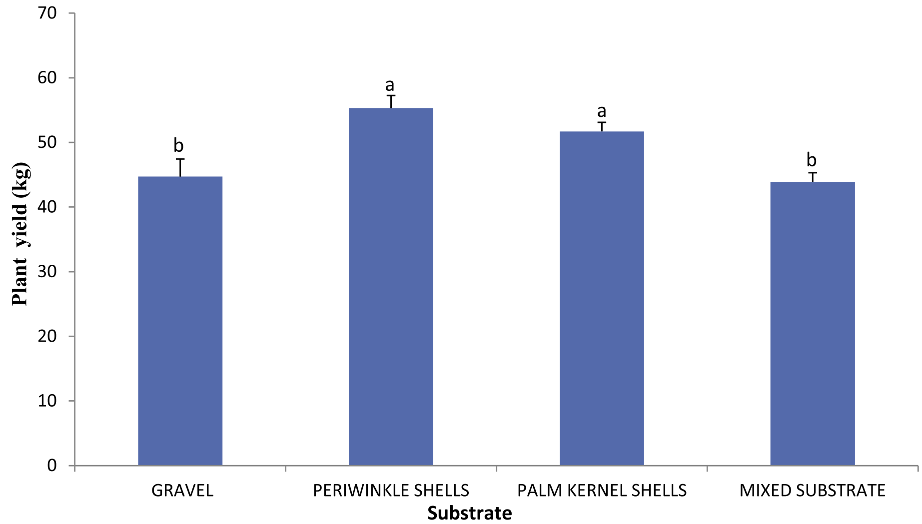

Fig. 7. Pumpkin yield in different substrates of an aquaponics system. Data shown are Mean ± SE. Bars with different letters are significantly different from each other ($P \leq 0.05$).

the plant roots. Similar to the findings of this study, Mader (2012) had reported that the growth of lettuce plant (*Lactuca sativa*) was significantly higher with Coconut husk media compared to that of Gravel. They further linked their observations to the inability of the gravel to absorb sufficient water caring nutrients needed for the lettuce seed to germinate. Rakocy et al. (2006) had earlier mention this factor as one of the disadvantages of gravel as a growth media in aquaponics system. Despite this fact, the yield of the plant as observed in this study was appreciably high for all the media understudied. However, the growth slowdown of some plant parameter (e.g. leave area, vine length and the number of branches) in the 10th and 12th week of propagation may be an inherent characteristic of the life cycle of the plant since this was observed in all treatment. This assumption is in line with the sigmoidal vegetative growth pattern reported by Akoroda and Adejoro (1990) for the same plant.

In conclusion, this study demonstrates that PKS and PWS are suitable media beds in aquaponics production of fluted Pumpkin *T. occidentalis*. The fact that these materials are nonconventional and considered waste makes them affordable and readily available hence choice alternative to conventionally used substrate. Hopefully, as aquaponics systems gets popularity in sub-Saharan African, more waste can be turn to wealth as they find alternative uses in production systems such as this.

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