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Bioactive Potential of Physicnut(JatrophaCurcas [L]) Saponinsas a Substitute Nematicide for Okra's Root-Knot Nematode Disease

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Abstract: The higher plants have yielded a wide variety of active chemical compounds antagonistic to plant parasiticorganisms. Saponins within J. curcas plant parts were tested in the laboratory and screen house experiments for their bio-nematicidal activity against the root-knot nematode(Meloidogyne incognita) on okra. Crude saponins isolated from plant parts were evaluated against 30nematodejuveniles (J2s) for 24, 48, & 72 hours in incubation at 0, 5, and 10 ml in vitro.One hundred percent mortality was obtained withseedsaponins (30/30) at 10 ml and 72 h of incubation, while at 5 ml, Seed saponins also recorded highest mortality (23/30) at 72 h incubation.Results under screen house trial demonstrated the ability ofsaponins administered at 5 ml/pottosubstantially decrease root-gall index while boosting plant growth indicators such as plant heights, leaf area, leaf numbers, 100 dry seed weights and mucilaginous properties of okra on application of seed and leaf extracts ofsaponins over the untreated control plants with root-gall index of 4 (severely galled). Application ofleaf and seed extracts ofsaponinsnot only reduced root gall index to 1.40 (rarely galled) and 2.00(slightly galled) but significantly ($P<0.05$) enhanced Okra pod weights by 58 % (3.62 g).Inspite of the fact that, root saponins effectively reduced root-gall nematode index to 2.30 (slightly galled), its application together with seed saponins supported the productionofokra pods with highest 100 dry seed weights and mucilaginous property. This study no doubt unveils the strong nematicidal activity of Jatropha based phytochemical such as saponins in the management of plant-parasite nematodes. However, further research is needed to study the impact of Saponins in other kinds of soils and on other nematode species

Keywords:1. Jatropha curcas;2. Meloidogyne incognita;3. Mortality; 4.Okra yield;5.Saponins;6. Root-knot

Introduction

As we strive to move on from 'quick fix' solutions to a more sustainable holistic options of crop protection, the dangers associated with the use of synthetic chemical plant protection in agriculture cannot be over emphasized(FAO, 2001). The most dangerous and offensive of all is the persistent organic pesticides - POP's(SP-IPM, 2000). POP's which includes dieldrin, endrin, heptachlor, DDT, chlordane, aldrin, camphechlor (toxaphene) and mirex are known to take a very long time and sometimes decades to break down into harmless substances long after use. To make matters worse, there is evidence of long-range transport to parts of the world, where they have never been used. POPs are thus having widespread, long-term health and ecological consequences that were never anticipated before use.

Methyl bromide nematicide, for instance, is extremely toxic to human health and environment, depleting ozone layer while acting as a broad-spectrum biocide that kills both target and nontargetsoil flora and fauna vital for agricultural production. However, despite the ban on the use of these dangerous chemicals (Mo̎rner, 2002;Dubby 2010), their use has continued relentlessly among farmers due to the absence of available alternative options which are as effective as synthetic pesticides.

Over time, root-knot nematodes have been controlled in various ways which includes inclusion of non-host in rotation sequence, flooding, organic additives to soil, bio-control agents, resistant cultivars, use of botanicals and chemical nematicides.(Khan et al., 2019;Agu et al., 2013). Although, synthetic nematicides appear to be more predominant because of their'quick fix' action.But for as long as they are available, farmerswill continue to rely on them not minding the immediate and long-term endangering effect they are likely to cause to the environment and the wellbeing of man.

A wide range of active compounds that are antagonistic to plant parasitic organisms have been produced by higher plants. Plant parts can produce metabolites or phytochemicals, which may serve as a source of novel organic nematocidal compounds. A typical plant with such potential is the Physicnut. A medicinal plant that is not only endowed with rich sources of secondary metabolytes but contains biological active phytochemicals amongst which are Saponins(Igbninosa et al., 2011; Devappa et al., 2010). According to Tava and Avato (2006), saponins exhibit a variety of biological and pharmacological characteristics, including molluscidal, anti-inflammatory, antimicrobial, and cytotoxic effects.

With the rise on the use of plant extract as alternative nematicides, optimization of their usage has been hindered by inadequate information on the role played by active components of such plants in disease control for improved yield. The present study was therefore conducted to evaluate the nematicidal potential of

physicnutsaponins on the okra root-knot nematode M. incognita under invitro and invivosituations

Materials and Methods

Experimental location

Situated55m above mean sea level at Latitude 5° 27' 50.23" North and Longitude 07° 02' 49.33" East, the trials were carried out in the Department of Crop Science and Technology screen house at Federal University of Technology, Owerri. This area features an Agro-forest rain forest ecosystem with over 2500 mm of annual rainfall, an annual temperature of 27–29°C, and a humidity range of 89–93%. Root-knot nematodes (M. incognita) are reported to be naturally present in the loamy sand soil (Eisenback et al., 1981; Agu, 2008).The study was repeated twice, and the mean taken for most parameters since data were similar.

Plant Material and Isolation ofSaponins

Fresh physicnut plant parts or sections (leaves, roots, and the seeds) were collected at Federal University of Technology, Owerri, Nigeria and taken to the herbarium of the department of Crop science and Technology where they were identified.They were thereafter spread out for drying in the shade for 5 days before being ground into powder using Thomas Wiley laboratory grinding machine and sieved through with a laboratory sieve of 212 mm aperture. It was then subjected to two rounds of soxhlet extraction: one using petroleum ether and the other using methanol. To produce solid residue, the extract was vacuum dried using a Rotary Vacuum Flask Evaporator. The solid that was left over after drying weighed sixty grams. For 30 minutes, the solid residue was refluxed with 80% w/v ethyl acetate. To estimate the total saponin content of the plant drug, the solvent was decanted off the precipitate, filtered, dried, and weighed respectively (Amin et al., 2016).

Test for Saponins

After diluting the extract with 20 milliliters of distilled water, it was stirred for fifteen minutes in a graduated cylinder. Saponins were detected by the creation of a 1 cm layer of foam (Ushieet al., 2016).

Nematicidal assay

Crude saponins from plant parts were examined for their effectiveness against juvenile root-knot nematodes (J2s) after 24, 48, and 72 hours in incubation at 0, 5, and 10 ml in in vitro conditions. Petri dishes used were stored at room temperature (±30°c) on the laboratory table. After being exposed to each treatment for 24, 48, and 72 hours, dead and live juveniles (J2) were counted using an electronic stereomicroscope at a magnification of 100X. When the juvenile (J2) did not respond to a fine needle used as a physical stimulus, it was

deemed dead (Hong et al., 2007). The ratio of the number of juvenile deaths to the total number of juveniles was used to compute percentage mortality, which was then expressed as a percentage.i.e. % Mortality $= \frac{X}{N} x \frac{100}{1}$

Where X= Number of dead juveniles ($J_{2.}$)

N= Original number of juveniles ($J_{2.}$)

Experimental Design and Layout in the Screen house

By using five replications, a Completely Randomized Design was employed to conduct a 3 x 6 factorial experiment for the investigation. While physicnut had three levels of plant parts, the saponins under evaluation had six levels of rates considered. The experimental units consist of 90 pots in the screen house, each containing 4 kg of steam sterilized soil. On the okra plant cultivar (NHA47 - 4).

Planting

One hundred test okra cultivar (NH47-4) seeds were surface sterilized prior to planting. This was achieved by immersing in a 10% concentration of commercial sodium hypochlorite solution (NaOcl) and subsequently rinsed with tap water. The seeds were then placed on moistened filter paper inside of sterile petri dishes (labelled appropriately) so they could sprout. Before being inoculated, two sprouting seeds were sown into every potted soil, after which the seedlings were pruned down to just one plant for each pot. The National Horticultural Research Institute(NIHORT), Okigwe in Imo State, Nigeria provided the test okra cultivar that was utilized.

Nematode culture

The inoculum originated from theM.incognita (Kofoid& White, 1919) Chitwood, 1949 that has been maintained on A.esculentus (okra) in pot cultures. The okra plants' diseased galled roots were retrieved whole by flipping the containers to liberate the root system. One liter of water and several smaller-cut galled roots were placedinto a warren blender. In order to avoid killing the larval stage of the nematodes, the electric blender was permitted to run for three-second intervals. More water was added to the slurry to make it 1200 ml. A Petri-dish was filled with thirty milliliters (30 ml) of this mixture, and the larvae were counted under a stereomicroscope. In three counts, the average number of larvae was 430±1.50.

Inoculum application and phytochemical treatment

Twelve days after planting, okra cultivar was inoculated at the base of each plant with 100 ml (About 1200 infective larvae) of the slurry (inoculum) at the roots and then covered with sterilized soil. The stock saponins after extraction were diluted by adding distilled water to achieve the final concentration of 50 mg/ml using the formula $V_1C_1=V_2C_2$ (Nazet al., 2013). 7 days after inoculation, the base of the potted plants was administered with the treatments at: 0 (control), 1, 2, 3, 4,

and 5 ml per plant. The inoculated okra plants were kept in a screen house with sufficient ventilation and 30 – 32° C noted as the average temperature.The control consisted of inoculated plants that were not treated with saponins.

Growth and Yield Parameters Measurement

Data was collected on Leaf area (cm^2), Plant height (cm), Number of leaves, 100 dry seed weight (g) and Fresh pod weight (g).An RVT viscometer (Brookfield Engineering Laboratories mass, USA) equipped with a No. 1 spindle set at 15 r.p.m. (15 revolutions per minute) was used to measure and read the mucilaginous characteristic of okra fruits. The mean was calculated for each treatment after this process was done three times (Sopadeet al., 1992).

Infection Assessment

Ten weeks after inoculation, root-gall infection assessment was carried out after all parameters related to growth and yield have been recorded.The degree to which M. incognita infected the roots during each treatment was determined by ensuring that the root systems were recovered intact. The potted plants were inverted to free the root system of adheringsoil. Roots were rinsed in water to get a clearer view of the galled roots to be assessed. Thereafter, root systems were examined and scored in line with the Infection scale of Agu and Ogbuji (1996) in which

0 = No infection (there are no galls).
1 = Infection that is rare (1-3 galls present)
2 = Slight infection (4-10 galls)
3 = Moderate infection (11- 30 galls) and
4 = Severe infection (30 galls or more present).

Statistical Analysis

When significant, means were separated using the Least Significant Difference (LSD) at the 5% level of probability after the collected data were subjected to an analysis of variance (ANOVA) using GENSTAT Edition 4.Data on root-gall index was correlated with data on yield using SPSS version 22.0

Results

Results of this study showed that the percentage yield of saponins Isolated from J. curcas plant parts are as follows;Seed (10.68 %), Leaf (9.34 %) and Root (4.20 %). The bioactive effects of saponins isolated from J. curcas plant parts on juvenile second stage nematode larvae are therefore shown in Figure 1. Tested juvenile nematodes died massively ($P < 0.05$) as a result of the saponins extract. Highest mortality (30/30) was obtained at 10 ml ofseedsaponins when compared to mortality recorded at 5 ml (94 %) and zero mortality of nematode juveniles when placed in petri-dishes containing distilled water (control).

The majority of juvenile nematode deaths happened when they were exposed to saponins every 72 hours. Intervals of 48 hours of exposure came next. At 24-hour exposure intervals, the least number of nematode mortalitiesoccurred.Effect of Jatrophasaponins extracted from plant parts differed significantly ($p<0.05$)from one another at 5 and 10ml of treatment application. Seed saponins achieved 100 %mortality, this was followed by root saponins (98 %), and leaf saponins (96 %) at 10 ml. On the other hand, at 5 ml the following mortalities where obtained forseedsaponins(93 %), root saponins: (89 %) and leaf saponins: (74%).

Figure 2 showed that severity of root-gall nematode disease on Okra varied amongst saponins extracted from plant parts. Although, Root-gall infection assessment on all okra plants in the inoculated untreated (control) pots indicated a gall index of 4 (severely galled), there was a progressive decline in gall index with corresponding increase in saponins treatments applied. Lowest gall index was however, recorded at 5 ml application of leaf saponins (1.40 -rarely galled), seed saponins (2.00 -slightly galled) and root saponins (2.3 -slightly galled)

Table 1 displays the effects of saponins from Jatropha parts on the heights of okra plants, leaf areas, pod weights & 100 dry seed weights as affected by incidence of rootgalls on okra plants.Plants treated with varying rates of saponins extracts produced significantly ($p<0.05$) higher leaf areas, plant heights, pod weights and 100 dry seed weights and had less root galls than the severely galled untreated control plants

Theplant heights of okra treated with Jatropha leaf, seed and rootsaponins differed significantly ($p<0.05$). Maximum mean plant heights of 14.54 cm was obtained with a 5 ml application of saponins extract; these results differed significantly ($p<0.05$) from the other rates.Plant heights increased, with increased rates of saponins treatment application. However, highest plant height produced at 5 ml after planting was not statistically ($p<0.05$) different from plant heights produced at 4 ml of saponins. The effects of Saponins from Jatropha parts on okra leaf area showed that okra plants treated with different rates of saponins produced significantly ($p<0.05$) more leaf area and had fewer root-galls than the highly galled untreated plants. This was especially true for the 5 ml saponins application that resulted in the highest mean leaf area. In contrast, heavily galled okra plants grown on untreated plants produced the least leaf area. Highest leaf area produced by plants treated with 5 and 4 ml of saponins significantly ($p<0.05$) differed from the other rates and control. Application of Saponins from Jatropha parts significantly ($p<0.05$) affected leaf areas of plants. Leaf areas of plants which weretreatedwithJatropha leaf and seed saponins were significantly ($p<0.05$) higher than leaf areas from plants treated with Jatropha root saponins. However, there was no significant ($p<0.05$) difference in leaf areas between leaf and seed saponins treatments respectively.

Plants treated with saponins produced a significantly ($p<0.05$) higher number of pod weights and had fewer root-galls than the severely galled untreated plants. Okra mean pod weights rose as more saponins treatments were applied. Pod weights of okra treated with Jatropha leaf and seed saponins were significantly ($p<0.05$) higher than those treated with Jatropha root saponins. This was more so on application of 5 ml of the saponins. Again, plants treated with saponins produced okra pods with significantly ($p<0.05$) more 100 dry seed weights and had fewer root galls than the severely galled untreated pots. Mean 100 dry seed weights of Okra also increased with increased application of Saponins treatments. In contrast to the untreated (control) and other rates,the interactions between Jatropha parts and Seed/Root Saponins at 5 mls significantly ($p<0.05$) produced the highest100 dry seed weights. Plants treated with leaf saponins came after this.

Figure 3 illustrates how root-gall incidence and okra's mucilaginous quality are affected by saponins from various Jatrophaparts.Plants grown in pots treated with saponins produced okra with significantly ($p<0.05$) higher mucilaginous properties than severely galled untreated pots.When plants were treated with 5 ml of seed and root saponins, their mucilaginous properties were significantly ($p<0.05$) higher than when plants were treated with leaf saponins. This was especially true for the interactions between jatropha parts and saponins, which produced plants with higher mucilaginous properties than the untreated control and other rates in a significant ($p<0.05$) way. The least mucilaginous plants were those treated with leaf saponins.

Table 2 displays the correlation analysisof the root-gall index and yield attributes as affected by the saponins extracts in two trials. The findings demonstrated a negative and statistically significant correlation between the root gall index and yield attributes. The Mucilaginous property correlated positively and significantly with plant height inthetrials respectively. The same was true for pod weights, 100 dry seed weights, number of leaves and leaf area in bothtrials

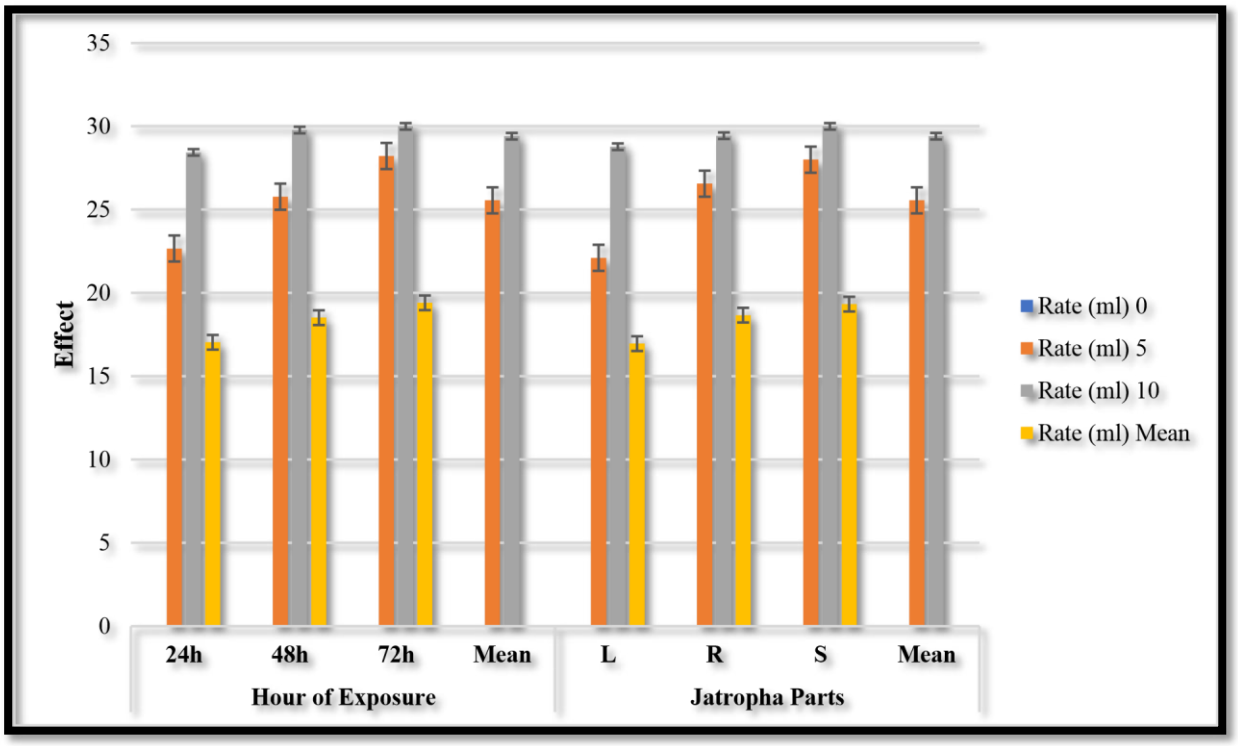

Figure 1: Effect of J. curcassaponins,plantpartsandexposurehour, on M. incognitamortality

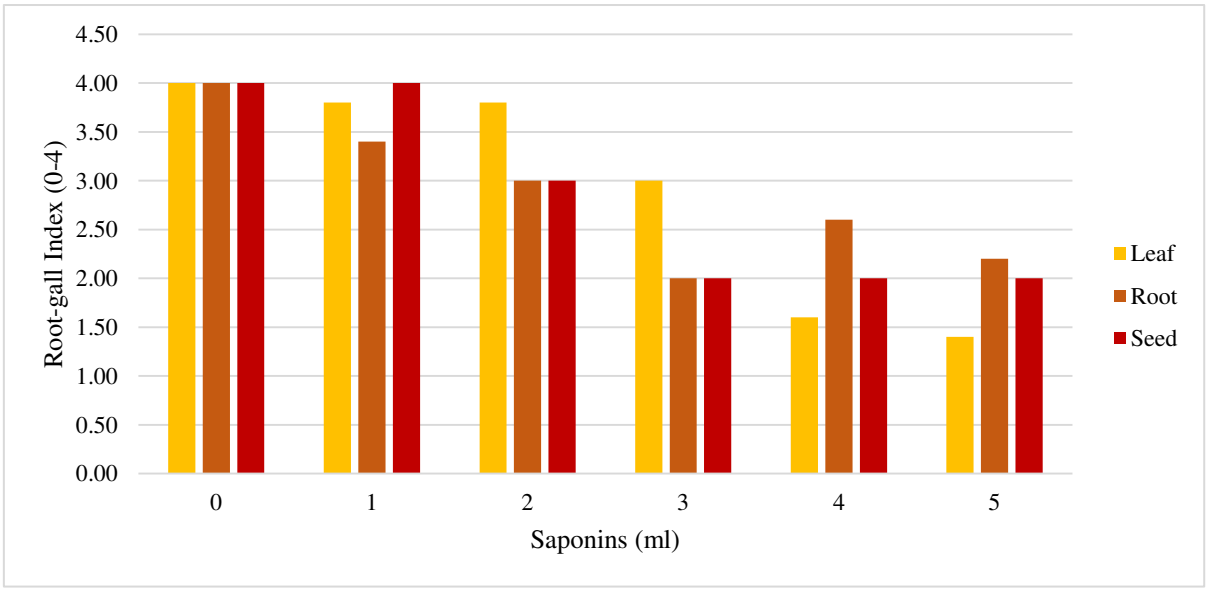

Figure 2: Effect of Saponins and Jatropha parts on root-gall nematode (M. incognita) Infection

Rating scale: 0 = No infection (No galls), 1 = Rarely (1-3 galls), 2 = Slight infection (4-10 galls)
3 = Moderate infection (11- 30 galls) and4 = Severe infection (30 or more galls present).

Table 1: Effect of Saponins and Jatrophacurcas parts on Okra Leaf areas, Plant heights,Podweightsand 100 dry seed weights as affected by root-gall nematode

	Plant heights (cm)				**Leaf areas (cm^2)**				**Pod weights (g)**				**100 dry seed weights (g)**			
	Jatropha Parts				**Jatropha Parts**				**Jatropha Parts**				**Jatropha Parts**			
Saponins (ml)	**Leaf**	**Root**	**Seed**	**Mean**	**Leaf**	**Root**	**Seed**	**Mean**	**Leaf**	**Root**	**Seed**	**Mean**	**Leaf**	**Root**	**Seed**	**Mean**
Untreated**(control)**	8.49	8.79	8.95	8.74	6.81	5.92	6.97	6.56	1.19	0.45	0.65	0.76	1.50	2.60	1.2	1.75
1	9.82	9.96	10.02	9.93	13	8.55	8.85	10.13	1.35	0.55	1.05	0.98	2.15	3.60	2.50	2.73
2	11.31	11.13	10.32	10.92	11.9	10.06	20.56	14.17	2.35	0.60	1.15	1.36	2.40	3.70	3.50	3.2
3	11.91	11.63	10.91	11.48	14.81	11.73	13.89	13.48	2.65	1.55	2.81	2.33	2.90	4.30	4.00	3.70
4	13.62	12.33	12.38	12.78	17.44	14.13	17.27	16.28	3.18	1.59	3.04	2.60	3.00	4.90	4.30	4.05
5	15.99	13.24	14.39	14.54	28.56	18.80	25.40	24.25	3.70	2.21	3.54	3.15	3.40	5.80	5.00	4.74
Mean	11.86	11.18	11.16		15.42	11.53	15.49		2.40	1.15	2.04		2.55	4.10	340	
$LSD_{0.05}$(Jatropha parts)		ns				3.65				0.01				0.10		

$LSD_{0.05}$ (Saponins)	1.26				5.14				0.02				0.10		
$LSD_{0.05}$(Jatropha part X Saponins)	ns				ns				0.04				0.20		

ns = not significant,

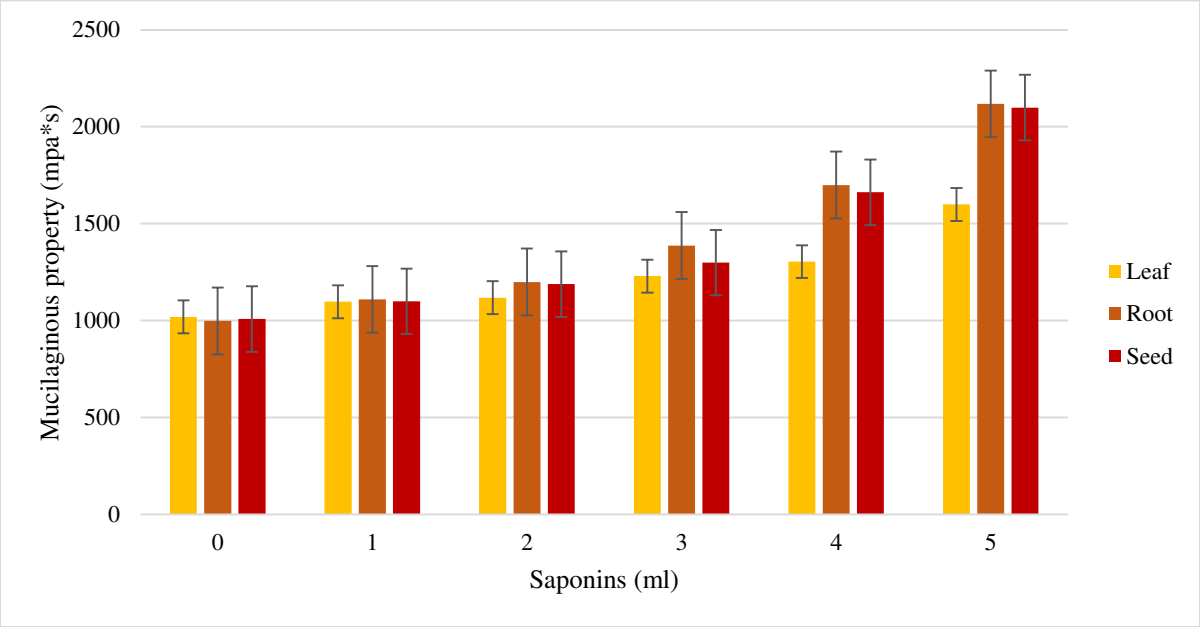

Figure 3: Effect of Jatropha parts and Saponins on the mucilaginous property of Okra as affected by root-gall nematode

Table 2: The linear matrix of correlation between root-gall indices and plant parameters as affected by saponins use for pot trials

1ST TRIAL	**PHT**	**LA**	**NLVS**	**PWT**	**HSWT**	**MUCIL**	**RGI**
PHT	1	.560**	.630**	.656**	.487**	.607**	-.658**
LA		1	.419**	.555**	.384**	.500**	-.439**
NLVS			1	.694**	.489**	.636**	-.614**
PWT				1	.391**	.620**	-.692**
HSWT					1	.857**	-.614**
MUCIL						1	-.659**
RGI							1
2ND TRIAL							
PHT	1						
LA	.537**	1					
NLVS	.647**	.311**	1				
PWT	.670**	.547**	.632**	1			
HSWT	.506**	.379**	.467**	.408**	1		
MUCIL	.580**	.502**	.476**	.610**	.846**	1	
RGI	-.588**	-.409**	-.387**	-.635**	-.603**	-.658**	1
LA = Leaf Area		PHT = Plant Height		HSWT = 100 Seed Weight			
NLVS = Number of Leaves			MUCIL = Mucilagineous property -mpa*s			RGI = Root-Gall Index	

Discussion

The percentage yield of saponins shows that its availability differs among the J. curcaspartswith the highest concentration in the seed, followed by the leaf and root respectively.The massive death of nematode juveniles observed when compared to the zero-mortality recorded in the untreated control reveals a display of nematoxic and anthelmintic activity due to the presence of saponins (Cavalcanti Gomes et al., 2016; Santos et al., 2018). Maestrinietal., 2020 also reported that saponins have a wide range of biological properties, including antimicrobial, fungicidal, cytotoxic, insecticidal and nematicidal activities. Corroboratively, saponins' biological actions are typically attributed to their unique interactions with cell membranes, which alter the permeability of the cells. Saponins alter certain components of the cell membrane, resulting in the production of micelle-like aggregates that lyse the membrane, impair its functionality, increase its permeability, and ultimately kill the parasites (Maestriniet al., 2020).

The higher nematode mortality observed in conjunction with the higher rate of saponin application correlates with comparable results byKepenekci and Saglam, 2015 who reported that higher concentrations of plant extracts were associated with higher death of nematode juveniles. Again, the higher nematode mortality correlating with longer treatment exposure periods(72 h) is consistent with the findings of Humairaet al., (2020), who found that plant extracts from Acaciamodesta plant sections showed the greatest larval mortality following 72 hours of exposure.

All untreated inoculated okra plants were observed to be severely galled due to root-gall nematode activity on the root. The primary signs of root-knot nematode infection, according to Castillo et al., (2001), are the noticeable giant cells (galls) formed on roots that are infected and excessive lateral growths on the roots. These symptoms reduce the ability of plants with infection to transfer nutrients and water from the soil to their vegetative organs.

Although, saponins extract of various plant parts substantially reduced gall index, Saponins extracted from physicnut seeds not only achieved 100% mortality of nematode but consistently gave a better performance both in the in vitro and in vivo study. This may be because of the concentration of one of the most toxic and active ingredients‘cursin’ which islocalised in the endosperm of the seed.(Devappaet al., 2010). This may also be the reason the seed has the highest percentage of saponins(10.68 %), whichconsistently achieved better results than the Leaf (9.34 %) and Root (4.20 %)saponins.

The plants in pots treated with different extracts of saponins showed a considerable improvement in growth and yield, with fewer galls than the extensively galled untreated control plants.Saponins are part of the active immune system of plants and function as natural antibiotics for plants. According to studies by Omar et al.,(1994), saponins have been shown to decrease the root-knot nematodeMeloidogynejavanica's overall population, number of egg masses, and viable juveniles.This may be because of their cytonematicidal effect on nematodes (Kuljanabhagavad and Wink, 2009).

The study's findings also demonstrated that the application of saponins raised, leaf areas, plant heights,pod weights and 100 dry seed weightsamong plants treated when compared to untreated plants. The effect of Saponins was observed to be most pronounced on application of Leaf and Seed Saponins. This may also be because Saponins content in the Leaf and Seed was more than Root Saponins as reported earlier[Seed (10.68 %), Leaf (9.34 %) and Root (4.20 %)]. By preventing the nematodes from exhibiting their virulence, the extract of saponins enabled the plants to utilize the nutrients in the soil to their fullest potential for growth and development. The root-knot nematodes' activity were the reason for the least amount of leaf area seen on severely galled okra plants cultivated in untreated pots.Root-knot nematodes has been reported to cause measurable changes in the morphology and physiology of the host (Williamson and Gleason, 2003).
The observed increases in the growth and yield parameters measured in the treated than the untreated plants were as a result of the nematicidal effect of the saponins treatment on the nematodes. Emeasor et al. (2002) stated that plant extracts exert nematicidal effects by disrupting the normal metabolic activities of organisms. This led to enhanced physiological activities in the treated plants. This further confirmed the findings of (Singh and Khurma, 2007; Maleita et al., 2012) who reported that plants heavily infested with root-knot nematodes exhibited stunted growth and poor yield and, in some cases, plants die even before reaching maturity. However, plants treated with saponins had nematode activity suppressed with enhanced physiological activity of the plant.

Interestingly, Increased mucilaginous property of okra was most prominent on plants grown on pots treated with 5 ml of seed and rootsaponins which performed better than leafsaponins. According to Ojiakoet al. (2015), higher rates of Jatropha extract yielded better performance, suggesting that the effect of concentration was dose-related.This contrasted the least pod weight and mucilaginous property recorded on highly galled plants in untreated pots.According to Agu et al. (2009), an

infection with root-knot nematodes decreased both the pod weight and mucilaginous quality of okra fruits.

In comparison to the untreated control plants, seed and root saponins yielded the highest 100 dry seed weightsat 5 ml. Plants administered leaf saponin treatments came next. This is in line with the reports of (Aguet al., 2013; Ahuchaoguet al., 2014;andOhazuikeet al., 2003), who at different times reported the nematicidal action of J. curcas's seed and root parts in field crops. The root-gall index and okra yields were shown to be negatively correlated, indicating that as galls increased, okra's growth and yield characteristics decreased. This could have happened as a consequence of aberrant cells (galls) interfering with the plants' ability to transfer moisture and nutrients (Abubakaret al., 2004). The okra plant's growth and yield attributes were enhanced and photosynthesis was boosted by increasing leaf area at a decreased galling response, as evidenced by the positive correlation observed across these variables; pod weights, one hundred dry seed weights and mucilaginous property.

Conclusion

The present study showed thatsaponins of J. curcas has great nematicidal potential as shown in thein vitro and in vivo experiments.Utilizing plant crude extracts with established bioactive components can help to reduce the dangerous effects of synthetic nematicides.Therefore, the crude saponin extracts discovered to be active in this study may be helpful in the creation of novel nematicidal agents. However, since to some extent, this researchhas its roots in the complex chemical interactions between plants and nematodes, more research is needed to determine the exact mechanism, type of action, and structure-activity relationship involved in J. curcas phytochemicals' ability to suppress nematodes.

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