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Effect of magnetic treatment of irrigation water on germination, growth, yield and popping-quality of popcorn under deficit irrigation

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Abstract

Popcorn is an important crop that is grown for consumption and snacks production in Nigeria however; it has low production and poor yield to meet the demand in the country. This study was conducted to determine the effect of magnetic treatment of irrigation water (MTIW) on the percentage germination (GP), growth rate (GR), popping-quality and yield of popcorn under deficit irrigation. MTIW was produced by passing the water through pipe surrounded with neodymium magnet rated 1.3 Tesla. Popcorn (FRESHTOP variety) was planted in 16 buckets for MTIW and 16 buckets for non-magnetic water (NMW, as control). Four levels of water application as the treatments with 100% water requirements (1.5 liters), 80% (1.2 liters), 60% (0.9 liters) and 50% (0.75 liters) were applied to the popcorn irrigated with MTIW or NMW and monitored for 100 days. The popcorn was thinned to 1 bucket^{-1} and grown in a garden shed of 5 by 5m and 3m high at the center and 2.5m at the edges. GP of the popcorn at 100%, 80%, 60% and 50% for MW were 75%, 88%, 75%, 63% and for NMW, were 50%, 63%, 50% and 50%, respectively. Mean grain yield after shelled for 100%, 80%%, 60% and 50% with MTIW were 43.43, 50.86, 39.65 and 35.80 g/bucket and corresponding grain yield for NMW were 29.20, 39.43, 37.27 and 28.41 gbucket^{-1}. Water applied at 80% produced the highest yield. MTIW increased the yield of popcorn by 48.73%, 28.88%, 6.39% and 26.01% for 100%, 80%, 60% and 50%, respectively. MTIW is recommended for growing 'FRESHTOP' variety popcorn.

Keywords: germination; irrigation interval; magnetized water; paired t-test; popcorn; popping of popcorn

Introduction

Popcorn is a cereal crop belonging to the family of Poaceae and it is commonly grown for human consumption as popped corn, production of snacks, corn flakes and biscuits. The rapid increased in the use of popcorn for snacks and biscuits in industries has greatly promoted the growers of popcorn in Nigeria to meet the high demand. Iken and Amusa (2004) reported that the demand for popcorn has increased in Nigeria about five decades ago that stimulates its production in savanna regions of the country especially in Zaria, Jos, Ilorin and other savanna areas. The popcorn varieties commonly grown in Nigeria have problem of low yield, low popping quality and inadequate availability of the popcorn for the industries for snacks production. The low yield could be due to poor soil fertility, local varieties, inadequate rainfall or irrigation to meet the water

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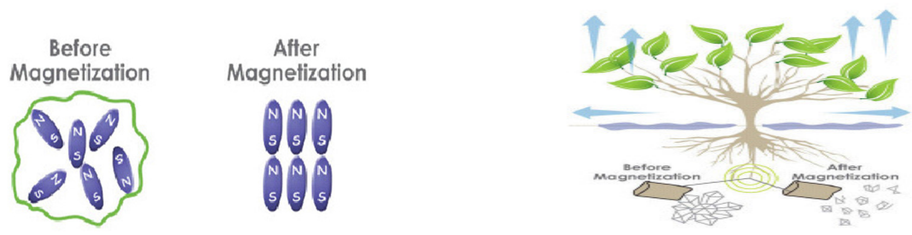
requirement by evapotranspiration of the popcorn. There is a need for economical methods for increasing the yield of popcorn in addition to the use inorganic fertilizer to improve the soil fertility and boost the yield. The method must be simple, economical, environmentally friendly and non-chemical method which could not adversely affect the soil, the crop and the man that would consume the popcorn. Farahnaky *et al.* (2013) reported that moisture content of the grain of the popcorn affects the popping quality and volume-expansion of the popcorn. Alattar *et al.* (2019) indicated that popcorn has a very hard endosperm and the starch in the endosperm with moisture content of 13-14% expands when heated and pericarp ruptures during popping.

Magnetic treatment of irrigation water (MTIW) which is also called magnetized water for irrigation is a simple method for increasing the germination percentage of cereal crops, accelerating the growth rate of crops and it could improve the yield of many crops (Babu, 2010; Abd-Ellateef and Mutwali, 2020). It is a non-chemical method that is environmentally friendly for improving the agricultural produce. Magnetized water is produced by allowing water to flow through magnetic field. The magnetic field would breakdown the water molecules into very smaller water molecule clusters, reduced the surface tension and restructured the water clusters into well-organized molecules and this makes magnetized water to be easily absorbed by plant and other materials (Malathy *et al*., 2017). Babu (2010) pointed out that magnetic field reduced the surface tension of water and increased the solubility of the water which could allow magnetized water to dissolve more elements from the soil thereby making the nutrients in the soil more available for plant growth. Magnetic treatment of irrigation water is beneficial and economical for crop production in areas where fertilizer is not readily available to improve soil fertility. Yusuf and Ogunlela (2017a) pointed out that magnetized water allowed more precipitation of macro-elements from the soil and high percentage of elements could be dissolved in magnetized water which could be used by plant. Yusuf and Ogunlela (2017b) reported that tomato plant easily absorbed magnetized water than non-magnetized water by evapotranspiration which could make more nutrients available for plant growth and better performance.

Magnetic treatment of irrigation water has been used in the field of agriculture for improving the nutritional quality of tomato (Yusuf and Ogunlela, 2016), high yield of chill pepper and maize (Babu, 2010). Helaly (2018) pointed out that magnetized water increased the growth rate and yield of tomato (Babu, 2010). Abou El-Yazied *et al*. (2011) indicated that magnetic field strength and the duration of exposure of the water to magnetic field affect the germination traits of different seeds. Magnetized water significantly increased the availability of soil nitrogen, phosphorus and potassium for plant growth (Maheshwari and Grewal, 2009). Abd Ellateef and Mutwali (2020) stated that irrigating plant with magnetized water increased the germination percentage of broad bean. Kney and Parsons (2006) pointed out that magnetized water could be used to reclaim soil and reduced soil moisture stress. Rawabdeh (2014) indicated that magnetically treated water significantly increased essential elements (N, P and K) uptake when compared with plants irrigated with tap water (non-magnetically treated water as the control). ELshokali and Abdelbagi (2014) also pointed out that magnetized water improved the Calcium, Iron, Potassium and Zinc contents in seeds of onion, tomato, sunflower and popcorn which significantly increased the production quality of the plants compared to non-magnetically-treated water. Babu (2010) also showed the pictorial views of the molecules of water before and after magnetization as shown in Figure 1 a and b shows the molecules of water in the soil before and after magnetization. Figure 1b is presented that plant could easily absorb magnetized water from the soil for crop growth.

Maheshwari and Grewal (2009) reported that magnetic flux density ranging from 350 to 1,360 G (measured inside the pipe where water is flowing) was effective for magnetic water treatment. Chern (2012) used permanent magnet with magnetic field strength of 5500 G for treating water which was used for irrigating lady's finger moench plant (okra) and the effect on plant growth and yield was significant. Podlesny *et al*. (2004) pointed out that for effective magnetic treatment, the detention period of water in the magnetic field should be at least 15 s while Aladjadjiyan (2007) reported that a detention period of 1-10 minutes is required for effective treatment of water in a magnetic field.

Deficit irrigation is an irrigation practice in which water requirement of crop is not fully supplied to crop during the irrigation. It done by reducing the quantity of water required for the irrigation by certain percentage during vegetative growth and it is normally practiced in order to maximize profit especially in area where water is scarce and the cost of water for irrigation is high. Deficit irrigation normally affects plant growth and yield due water shortage especially during flowering stage when water is mostly needed for fruit formation and development. The crop coefficient of popcorn varied from 0.45 - 1.25 at vegetative growth to flowering stage. The objectives of this study were to determine the effect of magnetic treatment of irrigation water on the germination percentage of popcorn, to determine the effect on growth rate and the yield of popcorn under different levels of water application (deficit irrigation) in a garden shed.



a) b)

Figure 1. Molecules of water before and after magnetization
Source: Babu (2010)

Materials and Methods

Location of the study

The study was conducted at the Demonstration Farm of the Department of Agricultural and Biosystems Engineering (DFDABE), University of Ilorin, Ilorin, Nigeria. University of Ilorin is located in Ilorin South Local Government Area of Ilorin city, Kwara State. Ilorin lies on latitude 8°30^{1}N and longitude 4°35^{1}E, with about 340 m above the mean sea level (Ejieji and Adeniran, 2009; Akpenpuun and Busari, 2016). Ilorin is located in the Southern Guinea Savannah of Ecological Zone of Nigeria with mean annual rainfall of about 1,300 mm with wet season begins at the end of March and ends by the ending of October while the dry season starts in November and ends in March (Ogunlela, 2001). The mean maximum temperature of Ilorin is 38 °C with mean relative humidity of 77.50% and daily mean sunshine hour of 7.1 h (Olanrewaju, 2009).

Preparation of the magnetized water

The water used for irrigating the popcorn was collected at the downstream end (50 m away from the dam) of the University of Ilorin dam. The magnetized water was produced in the laboratory by passing the water through the magnetic field and the magnetized water was then taken to the garden shed where the popcorn was planted in the buckets. The magnetic treatment unit comprises a hose of 25.4 mm diameter and 450 mm long surrounded with permanent magnets from the worn-out loud speaker with magnetic flux density 0.35T (3,500 G). The hose is connected to a rectangular pipe (15 by 50 mm and 450 mm long) which has 12 pieces of 10 mm × 25 mm × 50 mm neodymium magnet rated 1.3 T (13,000 G). The magnetic flux density inside the hose through which the water flows was 997 G measured using a gaussmeter (with Model GM-2 by Alpha Lab Inc) but the magnetic flux density inside the pipe surrounded neodymium magnet was 2,230 G. The water was allowed to flow through the magnetic field for 110 s so that it could be effectively magnetized. The magnetic treatment unit for producing the magnetized water is shown in Figure 2. The molecular structure of the water before and after magnetization is shown in Figure 3.

Figure 2. Magnetic treatment unit for producing the magnetized water

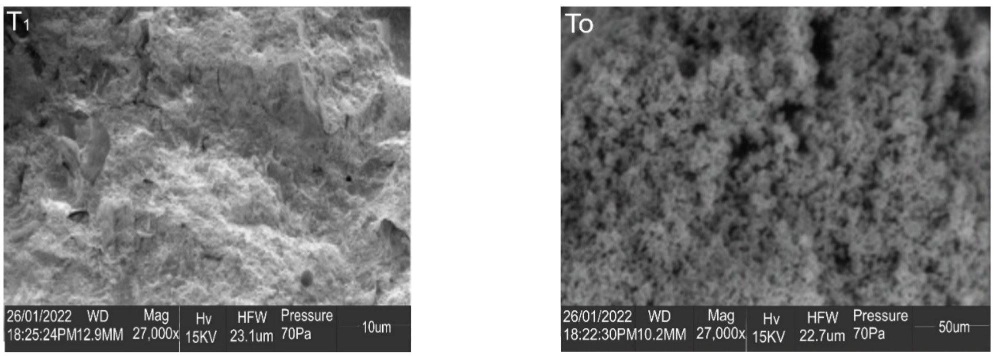


Figure 3. Molecular structure of the water before and after magnetization
T_1 = Magnetically treated water; To = non-magnetically treated water (Magnification SEM = 27000×)

Determination of water requirement and irrigation interval

Crop water requirement involves determination of crop evapotranspiration, available water of the soil, field capacity of the soil, wilting point, net depth of irrigation, irrigation interval and volume of water to be supplied during irrigation. Equations (1), (2), (3), (4), (5), (6), (7) and (8) were used to determine the crop evapotranspiration (ET_c), Wilting Point (WP), Available Water (AW), Net depth of irrigation (d_n), irrigation interval (i_v), Volume water needed per day per plant (V_{dp}), Volume of water needed for the irrigation (V_{ib}) and total volume of water required for irrigation of the farm (V_t), respectively.

$$ET_c = k_c \times ET_o \quad (1)$$

$$WP = \frac{FC}{F} \quad (2)$$

$$AW = \frac{\rho_b}{\rho_w}\left(\frac{FC - WP}{100}\right) D_r \quad (3)$$

$$d_n = P_n \times AW \quad (4)$$

$$i_v = \frac{d_n}{ET_c} \quad (5)$$

$$V_{dp} = ET_c \times A_b \quad (6)$$

$$V_{ib} = V_{dp} \times N_p \times i_v \quad (7)$$

$$V_t = V_{ib} \times N_b \quad (8)$$

Where crop evapotranspiration = ET_c (mm/day), k_c = crop coefficient, ETo = reference evapotranspiration (mm/day), AW = available water (mm), ρ_b = soil bulk density (g/cm^3), ρ_w = density of water (g/cm^3), FC = soil field capacity (%), WP = soil wilting point (%),F = percentage of silt in the soil which varies from 2.0 -2.4 but 2.2 was used in this study in Equation (2), dn = net depth of irrigation (mm), i_v = irrigation interval (day), N_p = number of plant to be irrigated, A_b = area of the bucket used (m^2), V_{dp} = volume of water required per day per plant (m^3 or liter but liter was used), V_{ib} = volume of water required for the irrigation per bucket (liter) and V_t =total volume of water required for irrigation of the farm (liter).

Planting of the popcorn in the garden shed

The garden shed where the popcorn was planted is 5 by 5 m, 3 m in height at the centre and 2.5 m high at the two edges so that rain water could fall down easily in case of rainfall during the experiment, The top garden shed was covered with a transparent nylon, 1 m from the top of the garden shed was also covered with the transparent nylon but 1.5 m from the ground surface was left uncovered with nylon for easy ventilation of the garden shed. The height of 1.5 m that was not covered with the nylon was covered with 2 mm wire mesh (wire screen) to prevent the entrance of rodents, birds and some insects that could attack the plant and destroy it during the study.

The popcorn ('FRESHTOP' variety) was planted in 32 plastic buckets on 1st March, 2021, 16 buckets for water treated with magnetic field (magnetic treatment of irrigation water) and 16 buckets for non-magnetized water (control). Each bucket has a diameter of 280 mm and 330 mm high but the soil was filled to 250 mm height and each bucket contained 13 kg of sandy loam. The soil was top soil collected from the same area and thoroughly mixed together to have a homogenous soil in term of fertility before putting it in the bucket where the popcorn was planted. A Completely Randomized Design was used, 4 levels of water application as the treatments were used for the popcorn irrigated with magnetized water or non-magnetized water. The irrigation interval computed using Equation (5) for the study regardless of the quantity of water applied was 3 days. This means that irrigation was done every 3 days for magnetized water or non-magnetized popcorn plant. The four treatments were the water supplied at 100% of available water (1.5 liters), 80% of available water (1.2 liters), 60% of available (0.9 liter) and 50% of available water (0.75 liter). Each treatment was replicated 4 times. The popcorn seed was planted 4 cm deep below the soil surface in each bucket with 8 popcorn seeds per hole but thinned to 1 popcorn crop per bucket. No fertilizer was used in this study and the popcorn plant was monitored for 100 days before it was harvested. The chemical properties of the soil used for growing the popcorn in the garden shed were shown in Table 1. The chemical properties of the soil were determined at the laboratory of the Department of Agronomy, Faculty of Agriculture, University of Ilorin, Nigeria.

Table 1. Chemical properties of the soil

Parameter	Value
pH	5.60
N (%)	0.71
P (mg/kg)	3.25
Ca^{2+}(cmol/kg)	1.68
Mg^{2+}(cmol/kg)	1.01
K^+(cmol/kg)	2.42
Na^+(cmol/kg)	1.18
Organic matter (%)	1.22
Organic carbon (%)	1.01
CEC (meq/100g of soil)	6.46

Measurement of the germination rate, growth rate and yield of the popcorn

The number of popcorn plant that germinated per bucket was recorded from the popcorn irrigated with Magnetized Water (MW) and Non-Magnetized Water (NMW) at different levels of water application to know the effect of water shortage on the germination rate of the popcorn. The growth rate was measured using a tape rule by measuring the height of the popcorn plant from the soil surface in the bucket to the top (terminal bud) of the plant. The popcorn was harvested 100 days after planting and shelled to determine the actual weight of the popcorn grain (yield of the popcorn). The popcorn plants during vegetative growth at maturity stage when it was ready for harvest was shown in Figure 4. The grain yield after shelled was determined using an electronic weighing balance as shown in Figure 5.

The popping-quality of the popcorn was determined by toasting the same quantity of popcorn grain sample (100 g) from popcorn irrigated with magnetized water supplied with 80% of available water and 100 g of popcorn grain sample from non-magnetized water with 80% of available water. The grain popcorn was put in the toasting machine toasted for 10 minutes. The popcorn for magnetized water and non-magnetized water were put on a flat plate and the pictures were snapped after toasting for observation and to see the popcorn that has better popping-quality.

A) B)

Figure 4. Popcorn with A) NMW at maturity and B) MTIW at maturity

A) B)

Figure 5. Determination of yield of popcorn A) NMW and B) with MW

Paired t-test statistical analysis

A paired t-test statistical analysis was used to check if the effect of magnetized was statistically significant on the growth and yield of the popcorn or not. The mean, the standard deviation, standard error and t-test values were calculated using Equations (9), (10a) or (10b), (11) and (12), respectively as given by Montgomery

(1998). The data used for the calculation of the paired t-test in Table 2 as an illustration was extracted from Table 5.

$$\overline{d} = \frac{\sum d}{n} \quad (9)$$

$$\delta = \sqrt{\frac{\sum d^2 - n(\overline{d})^2}{n-1}} \quad (10a)$$

$$\delta = \sqrt{\frac{\sum (d-\overline{d})^2}{n-1}} \quad (10b)$$

$$\delta_{Er} = \frac{\delta}{\sqrt{n}} \quad (11)$$

$$t_{cal} = \frac{\overline{d}}{\delta_{Er}} \quad (12)$$

where $\overline{d}$ = mean of the difference from x_1 and x_2, Σd = summation of *d*, *n* = number of the observations, δ = standard deviation, δ_{Er}= standard error and t_{cal}= calculated value of t-test.

Table 2. Data used for the computation of paired t-test value

MTIW	NMW	d = MTIW - NMW	d^2
173.72	116.82	56.90	3237.61
203.44	157.73	45.71	2089.40
158.61	149.08	9.53	90.82
143.22	113.65	29.64	874.38
n = 4		**∑d** = 141.71	**∑d²** = 6292.21

MTIW = Magnetic treatment of irrigation water, NMW = Non-magnetized water

$$\overline{d} = \frac{141.71}{4} = 35.42 \quad (9)$$

$$\delta = \sqrt{\frac{6292.21 - 4(35.42)^2}{4-1}} = 20.61 \quad (10a)$$

$$\delta_{Er} = \frac{20.61}{\sqrt{4}} = 10.31 \quad (11)$$

$$t_{cal} = \frac{35.42}{10.31} = 3.435 \quad (12)$$

But table value of t-test (t_{Table}) at $\alpha \leq 0.025$ and 3 degrees of freedom = 3.182

Similarly, the calculated value of paired t-test (t_{cal}) for the growth rate = 8.710

Results

Germination, growth rate and grain yield of the popcorn

Germination was assessed by the number of popcorn seeds germinated and the percentage of the popcorn germinated was presented in Table 3. The percentage levels of available water applied (100%, 80%, 60% and 50%) to the popcorn seed after planting affected the germination. Water applied at 80% of available water had the highest percentage germination (87.5% for MTIW and 62.5% for NMW) which was more than the percentage germination of other levels of the available water with 100% had 75.0% germination for MTIW and 50.0% for NMW as presented in Table 3. Water is necessary for germination and the result indicated that water supply at 50% of water requirement reduced the germination percentage by 50%. The growth rate of the popcorn plant was presented in Table 4. Magnetized water accelerated the growth rate of the plant with 80% of available water had the highest height, followed by 100%. The result for the grain yield of the popcorn was presented in Table 5. From Table 5, popcorn plant irrigated with magnetized water (water treated with magnetic field) produced the higher yield than the popcorn irrigated with non-magnetized water. The yields of the popcorn grain for both magnetized water and non-magnetized water at different levels of water application is shown in Figure 6.

Table 3. Percentage germination of the popcorn

Treatment	N_s	MTIW		NMW	
		N_g	P_g (%)	N_g	P_g(%)
100%	8	6	75.0	4	50.0
80%	8	7	87.5	5	62.5
60%	8	6	75,0	4	50.0
50%	8	5	62.5	4	50.0

N_s = number of popcorn seed planted, N_g = number seed germinated,
Pg = percentage seed germinated, MTIW and NMW were defined in Table 2.

Table 4. Growth of the popcorn plant

Days after planting (days)	Plant height (mm) of popcorn irrigated with magnetized water				Plant height (mm) of popcorn irrigated with non-magnetized water			
	100%	80%	60%	50%	100%	80%	60%	50%
32	254	270	220	217	230	248	204	202
39	335	415	250	242	320	338	230	225
46	371	460	302	298	360	380	271	264
53	412	493	321	314	382	407	290	283
60	433	514	344	338	404	428	307	302

Table 5. Yield of the popcorn (grains only) after shelling

Row	Yield of popcorn irrigated with magnetized water (g/bucket)				Yield of popcorn irrigated with non-magnetized water (g/bucket)			
	100%	80%	60%	50%	100%	80%	60%	50%
1	29.82	38.10	35.50	35.10	27.02	36.50	27.27	21.20
2	52.50	49.33	23.20	41.00	34.40	22.22	35.78	35.32
3	33.70	57.21	50.11	24.02	32.10	43.73	45.82	31.33
4	53.20	58.80	49.80	73.10	23.30	50.28	20.21	25.80
Total	**173.72**	**203.44**	**158.61**	**143.22**	**116.82**	**157.73**	**147.08**	**113.65**
Mean	**43.43**	**50.86**	**39.65**	**35.80**	**29.20**	**39.43**	**37.27**	**28.41**

MW = Magnetized Water (Magnetic treatment of irrigation water)
NMW = Non-Magnetized Water

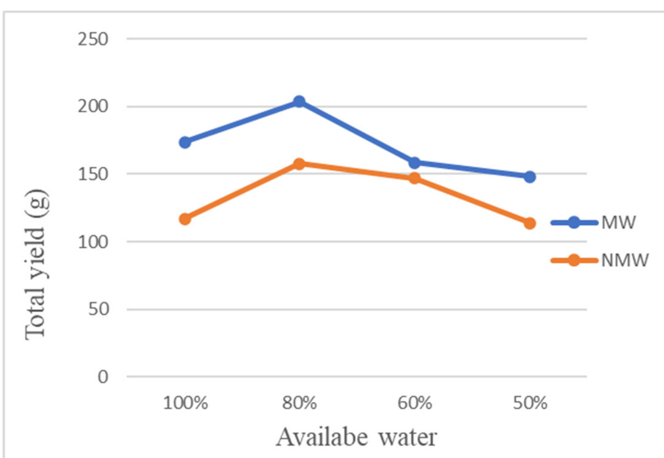


Figure 6. Yield of the popcorn at different levels of available water applied
MW = Magnetized Water (Magnetic treatment of irrigation water); NMW = Non-Magnetized Water

Discussion

Water is necessary for germination and the result indicated that water supply at 50% of water requirement reduced the germination percentage by 50%. From Table 3, magnetic treatment of irrigation water enhanced the germination of the popcorn seed because plant can easily absorb magnetized water than the non-magnetized water which could accelerate the germination rate as reported by Yusuf and Ogunlela (2017c). Abou El-Yazied *et al.* (2011) stated that magnetic field strength; duration of exposure of the water to magnetic field and irrigating crop with magnetized water enhanced the germination traits of different seeds. El-Gizawy *et al.* (2016) concluded that magnetic field improved the germination percentage, growth rate and yield of potato. Malathy *et al.* (2017) reported that magnetized water has a better quality with smaller water molecule clusters that could be easily absorbed by plant roots and could easily penetrate through the tissue of the crops. This could enhance the germination of seed like popcorn and other crops.

The growth rate of the popcorn plant presented in Table 4 indicated that magnetized water accelerated the growth rate of the plant with 80% of available water had the highest height, followed by 100%. The result of growth rate of this study agreed with studies of Babu (2010) and El - Sayed and Sayed (2014) that magnetized water increased the growth rate of green pepper and broad bean, respectively. The effect of magnetized water was statistically significant on the growth rate of the popcorn using paired t-test with calculated value of 8.710 which is greater than the Table value of t-test (3.182) at $\alpha \leq 0.025$.

From Table 5, popcorn plant irrigated with magnetized water (water treated with magnetic field) produced the higher yield than the popcorn irrigated with non-magnetized water. It was expected that popcorn irrigated with the total amount of water requirement (100% of AW supplied to the crop) would produce the highest yield but popcorn irrigated with 80% of AW produced the highest yield for both magnetized water and non-magnetized water. The percentage increment of the yield of popcorn irrigated with magnetized water compared to popcorn irrigated with non-magnetized water for 100%, 80%, 60% and 50% of AW were 48.73%, 29.99%, 6.39% and 26.01%, respectively. The effect of magnetized water for irrigating the popcorn was statistically significant on the yield of the popcorn by Paired t-test with the calculated value of t-test was 3.435 which is greater than the Table value of 3.182 at $\alpha \leq 0.025$. The result of the grain popcorn yield of this study was in agreement with the study of Dhawi (2014) that magnetized water improved the performance and productivity of plants. The increased in yield of the popcorn in this study was also in agreement to the study of Hozayn and Abdul-Qados (2010) that magnetized water increased the growth rate, chemical constituent and yield of chickpea.

Popping quality of the popcorn

The popping quality of the popcorn irrigated with magnetized water and non-magnetized water was assessed based on the quantity and popping volume-expansion (popped volume) of the popcorn produced after toasting. Popcorn irrigated with magnetized water appeared to have a better popping quality than the popcorn plant irrigated with non-magnetized water as shown in Figure 7B. Magnetized water is softer than ordinary water which could enhance proper translocation of manufactured food substances and useful chemicals after photosynthesis to the storage organ of the plant easily and this could improve popping quality of the popcorn. The volume-expansion (popping) of the popcorn irrigated with magnetized water Figure 7B was higher than that the volume-expansion of popcorn irrigated with non-magnetized water as shown in Figure 7A.

A) B)

Figure 7. Popped volume of the popcorn by NMW (A); Popped volume of the popcorn by MTIW (B)

Moisture content of the popcorn affects the popping of the grain and it also affects the volume – expansion of the popcorn. Hoseney *et al*. (1983) stated that water in the kernel provides the driving force for expanding the kernel after the rupture of the pericarp when the popcorn is superheated during popping. During the popping of popcorn, the pericarp acts as a pressure vessel and the initial breaking of the pericarp affects the volume expansion of the kernel (grain) than the subsequent rupture of the pericarp (Hoseney *et al*., 1983). Srdić *et al.* (2018) concluded that moisture content of the popcorn grain popping volume and the optimum moisture content of the grain for best popping volume was 14%. Cañizares *et al.* (2020) reported that volume expansion of popcorn during popping depends on the genotype, physical characteristics of the grain, temperature during popping and the moisture content of the grain. Cañizares *et al.* (2020) also reported that moisture content was a critical factor for popping volume because it directly affects the pressure that is exerted inside the grains against the pericarp when heated which causes volume-expansion during popping and low moisture reduces internal vapour pressure required for expansion of the popcorn. Magnetized water has very smaller water molecule clusters, reduced the surface tension and restructured water clusters into well-organized molecules which could allow it to flow faster, penetrate through the any material or the pericarp, vapourizes quickly and exert pressure for volume expansion of the popcorn during popping (Malathy *et al*., 2017). These properties of magnetized water could be responsible for enhanced volume-expansion of the popcorn during popping.

Conclusions

Magnetic treatment of irrigation water (magnetized water for irrigation) accelerated the growth rate of popcorn plant Magnetic treatment of irrigation water enhanced the germination of the popcorn. Water deficit by 50% and 60% of available water reduced the germination percentage for both popcorn irrigated with magnetized water and non-magnetized water. Magnetic treatment of irrigation water increased the growth rate and yield of the popcorn. Magnetic treatment of irrigation water increased the yield of popcorn by 48.73%, 29.99%, 6.39% and 26.01% for 100%, 80%, 60% and 50% of available water applied, respectively. The effect magnetized water for irrigating popcorn plant was statistically significant on the yield. Magnetic treatment of irrigation water also increased the popped volume of the popcorn.

Magnetized water should be adopted in Nigeria and other countries for irrigating popcorn and other crops under irrigated farm for high yield and better quality. The effect of magnetized water on the toxicology should be investigated in further research.

Authors' Contributions

Dr. Kamorudeen O. Yusuf conceptualized the idea and gave out the topic, he provided the neodymium magnets, purchased the gaussmeter for measuring the magnetic flux density, he supervised the research and he wrote the manuscript. Rukayat O. Tokosi and Mubaraq Raji were the two B.Eng research students that carried out the research as their final year project, irrigating the popcorn plant, monitoring the growth rate and taken all the necessary data during the experiment. The research was self-funded by the Dr. Kamorudeen O. Yusuf, Rukayat O. Tokosi and Mubaraq Raji who are the authors of this paper. All the authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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