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Research Article

Effect of Water Quality on the Germination of Okra (*Abelmoschus esculentus*) Seeds

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Okra (*Abelmoschus esculentus*), a fruit vegetable consumed in several countries, especially in Africa, contributes to the fight against poverty and malnutrition due to its nutritional value. However, in Burkina Faso, its cultivation during the dry season that lasts about 9 months remains dependent on the availability of water resources. Thus, during this period that lasts about 9 months, because of this situation, okra producers are dealing with very diversified sources of water. However, the rehydration of seeds, which is the first step towards germination, depends mainly of the water. Therefore, the aim of the present study was to test the germinability of okra seeds under different irrigation waters in order to propose alternative sources. Thus, seeds of three ecotypes of okra (B2, G259, and L2) were germinated using five water types (dam water, wastewater from the sewage treatment plant (WTP), well water, dishwashing greywater, and distilled water). The results showed a significant influence of the water type on the germination velocity and the growth speed of the radicle. Indeed, using wastewater from the WTP, the germination velocity was very significantly lower than those obtained with the other sources ($P < 0.0001$). Furthermore, seeds irrigated with WTP wastewater germinated less than other water types. Nevertheless, the germination rate obtained with dishwashing greywater ($86.93 \pm 0.14\%$), which is not used generally in agricultural production, is comparable to the rates obtained with other water types. Furthermore, the study showed a significant effect of the ecotype on the germination rate ($P \leq 0.001$). In addition, dam water significantly enhanced root growth compared to WTP ($P < 0.0001$). In view of the results and because of water scarcity in Sahelian regions, dishwashing greywater, which is generally discarded, could be collected and used for the germination of okra.

1. Introduction

Agriculture is one of the locomotive driving sectors of the economy of Burkina Faso as it provides 90% of employment and 80% of export earnings [1]. Agriculture contributed 33% on average to the country's gross domestic product (GDP) from 1995 to 2015 [2]. Furthermore, it is a source of income for many disadvantaged people [3] and contributes substantially to food security. In Burkina Faso, many crops including fruits and vegetables are of socioeconomic importance, especially in market gardening. Okra is mainly grown for its fruits and used as a vegetable for the preparation of sauces and many foods. Its fruits and leaves contain calcium, iron, proteins, and vitamins [4, 5], which are dietary supplements necessary for the basic diet, constituted mainly of starch [6]. In view of its nutritional composition, okra could play a key role in the fight against malnutrition [7].

However, the obvious importance of okra does not prevent its culture from being neglected in Burkina Faso. Indeed, it is specifically grown by women who generally do not have access to large areas of arable lands. In fact a study has shown that 97% of okra producers found in west central Burkina Faso were women [8]. Besides, its culture during the dry season (that lasts 8 to 9 months in Burkina Faso) is facing problem of water scarcity. Water is an important factor in agriculture, and its presence is one of the main essential conditions for seeds germination since it allows rehydration of dehydrated tissues leading to germination [9]. In addition, it is the driving force for multiplication and elongation of cells, which contribute to the growth of the embryo of the seed. Thus, for vegetable production in the dry season, various sources of water are involved including the traditional wells [1], which are also used for drinking water. It is therefore necessary to find alternative sources to support okra cultivation in the dry season. However, the ionic composition of the irrigation water could influence germination [7] which is considered as all the processes that go from the beginning of the rehydration of the seed to the emergence [10]. Since germination is a key step in agricultural production, several sources of water available in the dry season will be tested to assess their impact on okra germination parameters.

The overall objective of this work is to know the seed germination behavior of three ecotypes of okra besides waters of different qualities. Specifically, it is to

(i) Determine the effect of irrigation water on the germinative performance of okra seeds

(ii) Evaluate the effect of water quality on the initial growth of the okra plant

2. Material and Methods

2.1. Plant Material and Germination Conditions. To conduct this study, three okra ecotypes (L2, G259, and B2) collected from the three climatic zones of Burkina Faso (Sudanian, Sudano-Sahelian, and Sahelian zones, respectively) were used. These ecotypes were chosen from a participatory selection on the basis of their agromorphological performance and consumer preferences [11]. The seeds of these ecotypes are characterized by a very low individual weight. Thus, the average weight of one seed of each ecotype determined after weighing using a 0.001 precision balance is 0.055 g for ecotypes B2 and G259 and 0.065 g for ecotype L2.

The seeds of the three ecotypes were germinated in 150 Petri dishes under laboratory conditions. Watering was done every two days with 5 ml of water per Petri dish. Five types of irrigation water collected from different sources were used: well water drawn from a concession, dam water of the city of Ouagadougou, dishwashing greywater collected from a household in Ouagadougou, and wastewater from the sewage treatment plant (WTP) of the city of Ouagadougou; distilled water was used as a control. Before watering, parameters such as pH, temperature, and conductivity were measured using a pH meter and a WTW 7310 conductivity meter.

The germination test was conducted under laboratory conditions where the Petri dishes were placed directly on benches. The luminosity of the laboratory is that of light bulbs and daylight during the day, and at night, light bulbs are extinguished and the test is submitted to darkness until daybreak. The temperature and relative humidity of the laboratory were also recorded daily at specific times (9 h, 12 h, and 17 h) using a thermohygrometer TFA Dostman™ 30.5015.

2.2. Determination of the Characteristics of Irrigation Water. The five watering sources were analyzed for their physicochemical properties:

(1) Sodium and potassium were evaluated using a flame photometer

(2) Calcium and magnesium were determined by titrimetry

The concentrations of the different ions calculated according to equation (1) are expressed in mEq/l:

$$C = \frac{z \times c}{M}, \tag{1}$$

where C = concentration (mEq/l), z = valence of the ion, c = concentration (mg/l), and M = molar mass (g/mol).

The sodium absorption ratio (SAR) was calculated according to the following equation:

$$\mathrm{SAR} = \frac{[\mathrm{Na}^{2+}]}{\sqrt{([\mathrm{Mg}^{2+}] + [\mathrm{Ca}^{2+}])/2}}, \tag{2}$$

where [C] = ion concentration, Na = sodium, Ca = calcium, and Mg = magnesium.

2.3. Experimental Design. Two factors were studied: (i) the ecotype with three levels (ecotypes L2, G259, and B2) and (ii) the type of irrigation water with five levels (distilled water, dam water, well water, dishwashing greywater, and wastewater of WTP).

The Petri dishes containing okra seeds were placed on a horizontal surface in the laboratory in five completely randomized blocks, corresponding to five treatments (types of water). Each block (treatment) included the 3 ecotypes, and each ecotype was represented by 10 Petri dishes containing 25 seeds per dish. Hydrophilic cotton has been used as a moisture-conserving substrate in Petri dishes with a diameter of 90 millimeters each.

2.4. Measured Parameters and Expression of Results

2.4.1. Number of Germinated Seeds. The assessment of germination was made by visual observation on the basis of the emergence of the radicle (Figure 1). Sprouted seeds were counted daily at the same time for one week after which, the final germination rate (FGR), germination speed (GS), average germination time (AGT) were determined:

(1) The final germination rate (FGR) at a given time corresponded in percent to the number of germinated seeds relative to the number of total seeds germinated [12] (equation (3)):

$$\mathrm{FGR} = \frac{\text{number of germinated seeds}}{\text{number of seeds tested}} \times 100. \tag{3}$$

(2) The germination speed (GS) corresponded to the number of seeds germinated by the duration of germination (equation (4)):

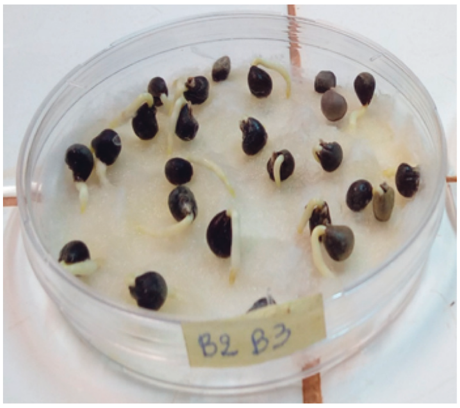

Figure 1: Germinated seeds of okra.

$$GS = \frac{\text{total number of germinated seeds}}{\text{duration of germination (in days)}}. \quad (4)$$

(3) The average germination time (AGT), which is the time after which 50% of seeds are expected to be germinated, is calculated according to the equation (5), used by [13] for a characterization test of shea seeds germination:

$$AGT = \frac{N_1 T_1 + N_2 T_2 + \cdots + N_n T_n}{\sum_{i=1}^{i=n} N_i}, \quad (5)$$

where N_1 = the number of seeds sprouted at time T_1; N_2 = the number of seeds germinated between time T_1 and T_2; and N_n = the number of seeds germinated between time T_{n-1} and T_n.

2.4.2. Growth of the Radicle. The length of the radicle (LR) was measured daily using a wire to follow the curvature of the radicle and a graduated ruler to obtain a constancy of values. The measurements were based on 20 germinated seeds per ecotype in each treatment. These seeds were selected and numbered from 1 to 20 and placed in another Petri dish, so that the radicles are convergent in the dish (Figure 2), before the start of measurements.

(1) The average lengths (AL) were calculated by the following equation:

$$AL = \frac{1}{n} \sum_{i=1}^{20} L_i, \quad (6)$$

where L_i = the individual length of the radicle of sprouted seeds and N = the total number of radicles measured.

(2) The growth speed (GrS) of the radicles was calculated following equation (7) by the ratio of the length over the time taken to reach this length [14]:

$$GrS = \frac{L}{T}, \quad (7)$$

where L = the length of the radicle and T = the time taken to reach this length.

2.5. Data Processing and Analysis. The data were processed using Microsoft Excel software for various calculations (germination rate, average germination time, average length, and growth speed).

The effect of irrigation water or ecotype on the germination parameters were determined through an analysis of variance using the software XLSTAT version 2016.02.27444. The Tukey test for comparison of averages was performed at 5% threshold.

3. Results

3.1. Physicochemical Characteristics of Irrigation Water. The physicochemical analysis of the irrigation water has shown that the water of the WTP contained more sodium (259 mg/l) and potassium (21 mg/l) than that from other sources. In addition, this water had an alkaline pH (8.26), higher conductivity (1284 μS/cm), and sodium absorption ratio (80.28) than other sources (Table 1). On the other hand, the distilled water used as a control, contained very small proportions of potassium, sodium, calcium, and magnesium and had a pH close to neutrality. Dishwashing greywater exhibited an acidic pH (5.57), with amounts of K^+ (1.73 mg/l), Ca^{2+} (0.56 mg/l), Mg^{2+} (3.11 mg/l), and conductivity (170.30 μS/cm) lower than that of dam water, well water, and WTP. The pH and conductivity values of this greywater appeared low compared to those obtained by [15] from mixture of laundry-dishwashing household greywater in rural areas (pH: 7.44–7.85; conductivity: 1178.17 μS/cm–2821.29 μS/cm).

3.2. Temperature and Relative Humidity of the Laboratory. The average daily temperature of the laboratory during the experiments varied between 28.20°C and 30.70°C, and the average relative humidity fluctuated between 69.67% and 78.33% (Figure 3). These temperatures are suitable for the germination of okra as it has been reported that the germination of okra requires optimal temperatures between 25°C and 35°C at ground level [16].

3.3. Germination Rate of Okra Seeds. Okra seeds germinated under the influence of the five types of water used for watering. This germination started two days after seeds sowing to reach a constancy from the 4th day to the 7th day for all watering sources. Globally, varying germination rates were obtained with different sources. Indeed, after four days, the germination rate obtained with distilled water and dam water were both of 90.67 ± 0.14%. On the other hand, with dishwashing greywater, the germination rate was 86.93 ± 0.14% at the same time (4 days). However, the analysis of variance did not reveal any effect of the water source as no significant differences between the germination rates were noticed (Table 2).

Figure 2: Convergent arrangement of the radicles of the seeds selected for the measurements.

Table 1: Physicochemical characteristics of waters used for watering.

Characteristics	Types of water				
	WTP wastewater	Dam water	Distilled water	Dishwashing greywater	Well water
K^+ (mg/l)	21	11.36	0.06	1.73	19
Na^+ (mg/l)	259	18.36	<0.04	33	65
Ca^{2+} (mg/l)	15.76	26.72	<2	0.56	13.68
Mg^{2+} (mg/l)	5.05	5.69	0.23	3.11	7.78
Conductivity (μS/cm)	1284	287	2.8	170.30	562
pH	8.26	7.49	7.72	5.57	5.97
SAR	80.28	4.56	<0.03	24.36	19.85

μS = microsiemens; SAR = sodium absorption ratio.

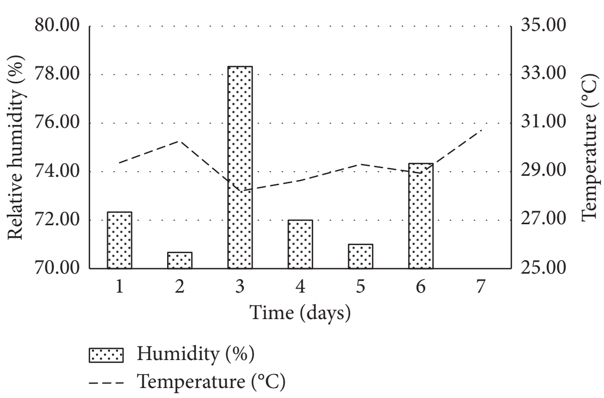

Figure 3: Evolution of temperature and relative humidity of the laboratory during the experiment.

The interecotype comparison showed that the seeds of the ecotype B2 gave the best germination with an average germination rate higher than that obtained with the seeds of the other ecotypes. The analysis of variance revealed a very high significant difference ($P < 0.0001$) between the ecotypes L2 and B2; a high significant difference between the ecotype G259 and the ecotype B2 ($P = 0.008$) and a significant difference ($P = 0.033$) between the ecotypes L2 and G259 were observed (Table 3). Indeed, this result is confirmed by grouping the averages by the Tukey test into three statistical groups (a, b, and c).

Table 2: Effect of watering water on the germinative performance of okra seeds.

Water type	Germination rate
Dishwashing greywater	$86.93 \pm 0.14\%^a$
Well water	$87.60 \pm 0.14\%^a$
WTP wastewater	$88.13 \pm 0.14\%^a$
Dam water	$90.67 \pm 0.14\%^a$
Distilled water	$90.67 \pm 0.14\%^a$

Values followed by the same letter are not significantly different from the statistical point of view.

Table 3: Effect of ecotypes on germination rate.

Ecotypes	Germination rate
L2	$84.88 \pm 1.03\%^c$
G259	$88.56 \pm 1.03\%^b$
B2	$92.96 \pm 1.03\%^a$
Interecotype comparison	P values
L2 ~ B2	<0.0001
L2 ~ G259	0.033
G259 ~ B2	0.008

Values followed by different letters are significantly different from the statistical point of view.

3.4. Germination Speed. Okra seeds germinated faster while irrigated with distilled water, with an average speed of 9.14 seeds/day (Table 4). However, the germination speed was slow when irrigated with WTP (8.44 seeds/day) compared to that obtained with other waters (Table 4). Analysis of

Table 4: Effect of watering water on the germination speed of okra seeds.

Water type	Average germination speeds (seeds/day)
WTP wastewater	8.43 ± 0.51^{a}
Dam water	8.89 ± 0.51^{b}
Dishwashing greywater	8.94 ± 0.51^{b}
Well water	8.99 ± 0.51^{bc}
Distilled water	9.14 ± 0.51^{c}
Interwater comparison	***P* values**
WTP wastewater ~ distilled water	<0.0001
WTP wastewater ~ well water	<0.0001
WTP wastewater ~ dishwashing greywater	<0.0001
WTP wastewater ~ dam water	<0.0001
Dam water ~ distilled water	≤0.001
Dishwashing greywater ~ distilled water	0.004

Values followed by different letters are significantly different from the statistical point of view.

variance showed that there is a very high significant difference between the germination speed of seeds irrigated with WTP wastewater and that of seeds irrigated with distilled water, well water, greywater, or dam water ($P < 0.0001$). In addition, there is a high significant difference between dam water and distilled water ($P < 0.001$) on the germination speed of okra seeds. There is also a significant difference ($P = 0.004$) between the germination speed of seeds sprinkled with dishwashing water and that of seeds sprinkled with distilled water. The grouping of average germination speeds according to water types by the Tukey test revealed three different statistical groups (a, b, and c): the WTP wastewater forms the slowest group (a) with a germination speed of 8.43 seeds/day + while distilled water with a germination speed of 9.14 seeds/day forms the more rapid group (c); the dam water and dishwashing greywater form the third group (b) with an intermediate germination speeds; well water with a germination speed of 8.99 seeds/day is not significantly different from group c nor group b.

Independently of the irrigation water, the germination speeds varied according to the ecotypes. However, the ecotype factor had no significant effect ($P = 0.54$) on the germination speed (Table 5).

Table 5: Effect of ecotypes on the germination speed of okra seeds.

Ecotypes	Germination speeds (seeds/day)
B2	8.84 ± 0.51^{a}
G259	8.88 ± 0.51^{a}
L2	8.92 ± 0.51^{a}

Values followed by the same letter are not significantly different from the statistical point of view.

3.5. Average Germination Time. The average germination time (AGT) is the time at which 50% germination is obtained. The results showed that the AGT varied according to the irrigation water but also according to the ecotypes. When distilled water was used, AGT was shorter in all ecotypes (40.56, 40.56, and 45.36 hours for ecotypes B2, L2, and G259, respectively), compared to that obtained with other watering sources (Table 6). The results showed that with WTP wastewater, it took longer time to get 50% germination. Indeed, WTP wastewater exhibited the longer AGT in all ecotypes (51.60, 52.08, and 52.56 hours for ecotypes G259, L2, and B2, respectively).

Table 6: Average germination time of the seeds of three ecotypes of okra according to the irrigation water.

Water type	Average germination time (hours)		
	B2	G259	L2
Dam water	45.84	45.36	48.96
WTP wastewater	52.56	51.60	52.08
Well water	45.12	45.12	45.6
Dishwashing greywater	45.36	46.32	46.8
Distilled water	40.56	45.36	40.56

3.6. Growth of the Radicle. The radicle growth expressed as its speed of growth and final length showed a variation according to the irrigation water. The best speed of growth (0.59 cm/day) and final length (3.54 cm) were obtained with dam water while the lowest growth rate (0.45 cm/day) and final length (2.67 cm) were recorded with WTP wastewater (Table 7). Indeed, analysis of the variance highlighted that dam water and well water significantly improved the radicle growth compared to the WTP wastewater ($P < 0.0001$), and to dishwashing greywater ($P = 0.002$). In addition, well water was proven to have better effect on radicle growth compared to dishwashing greywater ($P = 0.004$). The comparison of averages by the Tukey test revealed two distinct groups (a and b) for the growth speed as well as the length of the radicle. Distilled water was shown to have an intermediate effect on the radicle growth.

4. Discussion

Germination is the first step in the cycle of plant development. The germination of a seed is generally characterized by its duration and germination rate [17]. The germination rates of okra seeds irrigated with five different water sources, are very appreciable (>80%). These results could be justified in part by the internal and external conditions that seemed to be beneficial for the activation of metabolic reactions and the changes of physiological

Table 7: Effect of watering water on growth speed and final length of radicles.

Water type	Growth speed of radicles (cm/day)	Lengths of radicles (cm)
Dam water	0.59 ± 0.02^{a}	3.54 ± 0.13^{a}
Well water	0.59 ± 0.02^{a}	3.52 ± 0.13^{a}
Distilled water	0.52 ± 0.02^{ab}	3.10 ± 0.13^{ab}
Dishwashing greywater	0.48 ± 0.02^{b}	2.88 ± 0.13^{b}
WTP wastewater	0.45 ± 0.02^{b}	2.67 ± 0.13^{b}
Interwater effect comparison	P values	P values
Dam water ~ WTP wastewater	<0.0001	<0.0001
Well water ~ WTP wastewater	<0.0001	<0.0001
Dam water ~ dishwashing greywater	0.002	0.003
Well water ~ dishwashing greywater	0.004	0.004

Values followed by different letters are significantly different from the statistical point of view.

functions of the seeds, leading to the emergence of the radicle. Indeed, temperature is one of the external factors that influence the speed of metabolic reactions during germination, but the temperature necessary for germination varies according to the species. For the germination of okra, the temperature threshold is 16°C [18]. Ben Dkhil and Denden [19] found that the thermal optimum for germination of okra seeds was 25°C, but at temperatures of 10°C and 40°C, germination was totally inhibited. During our experiments, the ambient temperature of the laboratory varied between 28.20°C and 30.70°C (Figure 3). These temperatures would be favorable for the germination of okra. In addition, for all irrigation waters, germination began on the 2nd day after seedling to reach a constancy from the fourth day until the 7th day. Therefore, the duration of germination was 4 days for all waters. The difference in the physicochemical characteristics of waters, and especially the increase of the Na^+ concentration in the wastewater WTP, did not cause an increase in the duration of germination of okra seeds. Distilled water allowed a better germination speed of okra seeds with an average germination time of about 42 hours. These results could be explained by the fact that distilled water which contained almost no mineral elements with a very small amount of salts (Table 1) can be easily absorbed by the seeds. However, when irrigated with WTP wastewater, the germination speed was relatively lower and the average germination time was longer. The physicochemical characteristic of the water used for irrigation revealed the presence of a large amount of sodium ions (Na^+) in the WTP wastewater. The low speed of germination of the seeds watered with the WTP wastewater could be probably due to the salinity induced by the Na^+ ions present in this water and its high conductivity. Indeed, Benidire et al. [20] have shown that NaCl can induce a decrease in the germination speed of beans. Previously, it has been reported that an increase of the NaCl concentration of the medium caused a decrease in the germination capacity and in the germination rate [21]. Furthermore, during germination, salinity may cause a reversible osmotic effect and an irreversible toxic effect [20]. Thus, the low germination obtained with WTP wastewater could be attributed to an osmotic effect of this salty water on the germination of the seeds of okra. Indeed, the WTP of Ouagadougou receives industrial wastewater including from the brewery with high salinity. This osmotic stress due to the salinity of the WTP wastewater could have inhibited the germination. Besides, authors have shown that the salinity of the medium generally generates osmotic stress coupled with biochemical disturbances induced by the flow of sodium ions [22, 23]. Our results on average germination time are comparable to those reported by [24] who showed that seed AGT increases with salinity.

Moreover, the low germination speed and growth of the radicles obtained while watering the seeds with WTP wastewater could be explained by the high conductivity (1284 μS/cm) and the sodium absorption ratio (80.28). According to [9], the high conductivity of irrigation water can inhibit the extraction of this water by plants. However, salt concentrations of NaCl of the order of 1 g/l induced an increase in the germination rate, the growth of maize [25]. Dishwashing greywater had an effect similar to that of the dam water and that of the well water. On the AGT, it could be an alternative source for okra production provided its pH is suitable.

5. Conclusion

Okra seeds germinated quickly after 4 days when watered with all the five different sources. High germination rates were obtained (more than 80%) whatever the water source used. WTP wastewater has been shown to induce the slowest germination (germination speed) when the effects of watering sources were compared probably because of the high sodium content and conductivity. Dam water obtained the best growth speed and final length of the radicles compared to those obtained with the other waters. Of the sources tested, WTP wastewater presented the lowest speed and length of radicles. Dam water seems to be more suitable for the growth of Okra radicles than the water from other sources. Because of water scarcity in Sahelian region and considering the results obtained with dishwashing greywater, it could be used as an alternative source for okra germination. However, further studies on the effect of greywater on the development of the plant grown on soil are necessary.

Data Availability

The data used to support the findings of this study are included within the supplementary information file.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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Supplementary Materials

The file contains data on the germination of okra seeds under different types of water and the radicle growth parameters, which were used for the statistical analyzes of the tables contained in our article. (*Supplementary Materials*)

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