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January 2022
ISSN 1996-0824
DOI: 10.5897/AJPS
www.academicjournals.org

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Vol. 16(1), pp. 1-7, January 2022
DOI: 10.5897/AJPS2021.2158
Article Number: D0C8C6668392
ISSN 1996-0824

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African Journal of Plant Science

*Full Length Research Paper*

# Normalized difference vegetation index as screening trait to complement visual selections of durum wheat drought tolerant genotypes

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Received 12 May, 2021; Accepted 1 September, 2021

**Normalized difference vegetation index (NDVI) is considered as a potential screening tool detecting stay green traits for drought tolerance. The present study aimed to evaluate durum wheat genotypes using NDVI under drought condition and investigate its association to grain yield. NDVI scores taken at different growth stages for 64 durum wheat genotypes were replicated twice in both sandy clay and clay textured soils situated at the same geographic location of Debre-Zeit Experimental Station, Ethiopia during 2016 rainy season; also, Green Seeker (Hand held) was used to measure the quantity of photosynthetically active pigments in leaves. Measurements of NDVI were made four to five times on sunny days between booting to physiological maturity. Analysis of variance showed significant variation among genotypes at 0.01% on NDVI values across all growth stages except at physiological maturity in both sandy clay and clay soils. The NDVI scores were highly significantly associated with yield at grain filling and anthesis stages in both soil environments. Overall, it is possible to suggest that use of NDVI would help complement identification of drought tolerant genotypes on durum wheat.**

**Key words:** Grain yield, Normalized difference vegetation index (NDVI), *Triticum durum.*

## INTRODUCTION

Wheat is the fourth most important cereal crop after maize, tef and sorghum in terms of area coverage and production in Ethiopia. Both bread and durum are grown extensively in the country, although separate area coverage and production is not known. They are cultivated over an area of 1.69 million hectares with annual production of about 4.5 million tons (CSA, 2018). However, average productivity in the country is low (2704 kg/ha). Drought stress globally, under rain-fed based crop production system of Ethiopia is one of the largest causes of wheat yield reduction. Drought has particularly become a common problem in both lowland environment

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associated with early termination of rainfall and highland vertisols environment which is waterlogged and does not follow optimum planting time which usually results in late planting. Breeding and selection of genotypes for drought tolerance using grain yield alone has a number of constraints. Low heritability and genetic variance are among the major challenges while using grain yield for identification of genotypes under drought stress (Manal, 2009). High genotype × environment is also another challenge for selection of the right genotypes under drought stress (Sangam et al., 2020).

The use of NDVI to measure spectral traits associated with stay green for crop variety evaluation complementing visual selection is suggested to be the simplest and efficient tool for speeding up the selection cycle by reducing the time spent to evaluate germplasm under water stress condition and select genotypes earlier in the season or evaluate large number of genotypes during each round of selection and grain yield prediction before harvesting (Sanchez et al., 2013; Sruthi and Mohammed, 2015). Furthermore, estimating agronomic traits such as yield or drought indirectly using spectral traits measured proximally with handheld devices provides alternative solution to managing the constraints of phenotyping (Araus and Cairns, 2014).

Normalized difference vegetation index (NDVI) has been studied widely on a range of applications on drought (Seyoum et al., 2016), heat stress (Shanahan et al., 2001; Cao et al., 2019) yield prediction and nitrogen management (William et al., 2001; Syeda et al., 2014; Son et al., 2014; Quemada et al., 2019; Hassan et al., 2019), non-destructive biomass estimation (Semeraro et.al., 2019); disease management, (Sheedy and Thompson, 2009) on root lesion nematode and Mahlein et al., (2019) on fusarium head blight. According to Tardieu (2012), genotypes which maintain consistent and high NDVI values across different stages performed better under drought than those with low values, which ultimately resulted in higher biomass and yield under severe to moderate stress. Based on the existing knowledge, the question related to NDVI in breeding to drought could be to what extent the genotypes vary and traits can be associated with the final yield while using this selection tools for early variety selection.

The present study aimed to evaluate and identify durum wheat genotypes using normalized difference vegetation index under drought condition in two soil types of Debre-Zeit Experimental Station and determine its association to grain yield at different growth stages.

## MATERIALS AND METHODS

Sixty-four durum wheat genotypes of different origin were used in the study. Twenty-one of the genotypes were released cultivars, 21 of the materials were introduced breeding lines obtained from Centro Internacional de mejoramiento de maiz y Trigo (CIMMYT) and the remaining 14 materials ones were landraces (Table 1).

### Site description

The genotypes were grown in the field during the main rainy season in 2016 at Debre-Zeit experimental station which is located in 8° 41' 36" latitude and 39° 03' 17' longitude with altitude 1880 m.a.s.l. Soil data analysis were carried out at Agricultural and Nutritional Research Laboratory of Debre-Zeit Agricultural Research Center (MOALR, 2018) and the physical and chemical properties of the soils are presented in Table 2

### Experimental design and field management

The genotypes were planted in 8 x 8 simple lattice design field experiments with two replications on plots consisting of two rows 2 m in length and 20 cm between rows spacing. The genotypes were grown late in the season in sandy clay on August 1, 2016 and in clay soil on July 31, and were exposed to terminal moisture stresses uniformly from the date of anthesis which represent lowland wheat growing environment of Ethiopia. The planting date was selected based on the consistency of the incidence of drought and targeted timing to coincide at anthesis stage for the majority of the genotypes included in the study.

In the experiment, 100 kg of Di-ammonium Phosphate was applied at planting and split application of 100 kg of urea where one-third was applied at planting and two-third at time of tillering. The plots were hand weeded and a fungicide, tilt-250 with rate of 150 ml/ac was applied twice in the season to protect the genotypes from stem rust infection.

### Data collection

Five measurements of NDVI were recorded at different growth stages of the plants. The measurement were carried out on a fine sunny, wind free days on plant surface, holding the sensor of the handheld green seeker 50 cm above the stand (Govaerts and Verhulst, 2010). The measurements were taken during booting, heading, anthesis, grain filling and physiological maturity (Table 3). Yield data were recorded on plot basis after drying and threshing.

### Data analysis

Analysis of variance was performed using R-4.2 and linear correlations were employed to indicate associations between the parameters Minitab version-16.

## RESULTS AND DISCUSSION

### Analysis of variance

Analysis of variance showed significant variation among genotypes at 0.01% on grain yield and normalized difference vegetation index at all growing stages except at physiological maturity in sandy clay soils (Table 4) indicating that the genotypes respond differently to spectral reflectance. The results also exhibited a large difference on NDVI scores at different growth stages. For instance, the average NDVI record in sandy clay soil was 0.76, 0.63, 0.52, 0.37 and 0.16 at booting, heading, anthesis, grain filling and maturity, respectively (Table 4). In clay soil, the analysis of variance revealed that significant variation among genotypes at 0.01% on NDVI

**Table 1.** Names and sources of durum wheat varieties and breeding lines used in the study.

| No. | Name | Source | No. | Names | Sources |
|---|---|---|---|---|---|
| 1 | Arendato | Released variety | 33 | IL-PV-6 | CIMMYT |
| 2 | Cocorit | Released variety | 34 | LRPL-86 | Landrace |
| 3 | Boohai | Released variety | 35 | LRPL-215 | Landrace |
| 4 | Quamy | Released variety | 36 | IL-PV-20 | Landrace |
| 5 | Assasa | Released variety | 37 | IL-PV-17 | CIMMYT |
| 6 | Ginchie | Released variety | 38 | IL-ID-2 | CIMMYT |
| 7 | Ude | Released variety | 39 | IL-ID-3 | CIMMYT |
| 8 | Yerer | Released variety | 40 | IL-ID-4 | CIMMYT |
| 9 | Denbi | Released variety | 41 | IL-ID-5 | CIMMYT |
| 10 | Hitosa | Released variety | 42 | IL-ID-6 | CIMMYT |
| 11 | Werer | Released variety | 43 | IL-ID-7 | CIMMYT |
| 12 | Mangudo | Released variety | 44 | IL-ID-8 | CIMMYT |
| 13 | Mangudo | Released variety | 45 | IL-ID-9 | CIMMYT |
| 14 | Tob-66 | Released variety | 46 | IL-ID-10 | CIMMYT |
| 15 | Gerado | Released variety | 47 | IL-ID-11 | CIMMYT |
| 16 | Ejersa | Released variety | 48 | IL-ID-12 | CIMMYT |
| 17 | Utuba | Released variety | 49 | IL-ID-13 | CIMMYT |
| 18 | Toletu | Released variety | 50 | IL-N-8 | CIMMYT |
| 19 | Kilinto | Released variety | 51 | ID-N-11 | CIMMYT |
| 20 | Bichena | Released variety | 52 | IL-IDO-2 | CIMMYT |
| 21 | Flakit | Released variety | 53 | IL-IDO-3 | CIMMYT |
| 22 | LRPL-1 | Landrace | 54 | IL-IDO-4 | CIMMYT |
| 23 | LRPL-6 | Landrace | 55 | IL-IDO-5 | CIMMYT |
| 24 | LRPL-2 | Landraces | 56 | IL-IDO-6 | CIMMYT |
| 25 | LRPL-8 | Landraces | 57 | IL-IDO-7 | CIMMYT |
| 26 | LRPL-18 | Landraces | 58 | IL-IDO-8 | CIMMYT |
| 27 | LRPL-14 | Landraces | 59 | IL-IDO-9 | CIMMYT |
| 28 | LRPL-9 | Landraces | 60 | IL-IDO-10 | CIMMYT |
| 29 | LRPL-11 | Landraces | 61 | IL-IDO-11 | CIMMYT |
| 30 | LRPL-3 | Landraces | 62 | IL-IDO-12 | CIMMYT |
| 31 | LRPL-7 | Landraces | 63 | IL-NLM-3 | CIMMYT |
| 32 | LRPL-4 | Landraces | 64 | IL-NLM-13 | CIMMYT |

was recorded at different growth stages except at physiological maturity and grain yield. The NDVI recorded was 0.76 at booting, 0.70 at heading, 0.64 at anthesis, 0.52 at grain filling and 0.15 at physiological maturity (Table 5). The finding of this study suggested that the genotypes ability to absorb the reflectance is reduced due to senescence. Several authors (Syeda et al., 2014; Salah et al., 2015; Nasir et al., 2020) reported that NDVI scores reduced from the vegetative to reproductive stages and dropped to lower levels at physiological maturity.

The trends were similar in both soil types although the average values at each developmental stage in light textured soil was low and showed sharp reduction (Figure 1), indicating the existence of soil moisture variations in maintaining and supplying different soil types to the plant. Both sandy clay and clay soil showed a significant effect on the development of photosynthetically active leaf area. Plants raised under sandy clay soils had a mean NDVI value of 0.49, while that grown under clay soil was 0.55. Although the differences were not visible under visual evaluations when the measurements were carried out at booting and 50% heading, the records showed a significant reduction from booting to heading with mean value of 0.76 and 0.63 in sandy clay soil. The trend was similar and decreased from 0.76 at booting to average value of 0.70 at heading in clay soil. This indicates that there would be an effect on photosynthetically active leaf area. Likewise, NDVI recorded 10 days after heading showed a similar trend on the reduction of green area compared to the earlier stages in both soil textures.

The genotypes under sandy clay soil again showed low NDVI value (0.49) compared to clay pelli-vertisols (0.55) across different growth stages. The reduction of NDVI

**Table 2.** Physical and chemical characteristics of soil at Debre-Zeit experimental station.

| Type | Soil EC Ds/m | Soil %TN | Soil % C | Soil CEC Meg/100 soil | Soil pH | Class |
|---|---|---|---|---|---|---|
| Light | 0.12 | 0.08 | 1.00 | 18.9 | 7.3 | Sandy Clay |
| Black | 0.16 | 0.11 | 1.05 | 27.2 | 6.9 | Clay |

EC=Electrical conductivity, TN=total nitrogen, CEC=Cation exchange capacity.

**Table 3.** Crop developmental stages used for measuring normalized difference vegetation index at Debre-Zeit Sandy clay and clay soils, 2016 rainy season.

| Stage | Date of record | | Days after planting | |
|---|---|---|---|---|
| | Light soil | Black soil | Light soil | Black soil |
| Booting | 16 Sep. 2016 | 17 Sep. 2016 | 47 | 49 |
| Heading | 27 Sep. 2016 | 28 Sep. 2016 | 58 | 60 |
| Anthesis | 7 Oct. 2016 | 8 Oct. 2016 | 68 | 70 |
| Grain filling | 18 Oct. 2016 | 19 Oct. 2016 | 79 | 81 |
| Maturity | 02 Nov. 2016 | 03 Nov. 2016 | 95 | 97 |

Source: Alemayehu et al. (2019).

**Table 4.** Mean squares, minimum, maximum and means of grain yield (gm/1m$^2$) and Normalized Differences Vegetation Index (NDVI) values of 64 durum wheat genotypes tested at Debre-Zeit sandy clay soil. 2016 rainy season.

| SOV | Df | GY | NDVI BT | NDVI HD | NDVI AN | NDVI GF | NDVI MT |
|---|---|---|---|---|---|---|---|
| Rep. | 1 | 12551 | 0.004 | 0.022 | 0.011 | 0.023 | 0.00061 |
| Geno. | 63 | 3795** | 0.0076** | 0.017** | 0.015** | 0.008** | 0.00087$^{ns}$ |
| Error | 49 | 1675 | 0.003 | 0.0038 | 0.004 | 0.003 | 0.00078 |
| Min. | | 105.7 | 0.60 | 0.44 | 0.36 | 0.26 | 0.12 |
| Max. | | 323.6 | 0.84 | 0.76 | 0.66 | 0.50 | 0.21 |
| Mean | | 212.5 | 0.76 | 0.63 | 0.52 | 0.36 | 0.16 |
| CV(%) | | 20.5 | 8.1 | 14.6 | 16.6 | 17.8 | 13.3 |

SOV=Source of variation, NDVI BT=Booting, NDVI HD=Heading, NDVI AN=Anthesis, ND GF=Grain filling, NDVI=MT=maturity

**Table 5.** Mean squares, minimum, maximum and means of grain yield (gm/1m$^2$) and Normalized Differences Vegetation Index (NDVI) values of 64 durum wheat genotypes tested at Debre-Zeit clay soil 2016 rainy season.

| SOV | Df | GY | NDVI BT | NDVI HD | NDVI AT | NDVI GF | NDVI MT |
|---|---|---|---|---|---|---|---|
| Rep. | 1 | 416 | 0.000226 | 0.004395 | 0.000488 | 0.000612 | 0.00006 |
| Geno. | 63 | 5094$^{ns}$ | 0.005133* | 0.007143** | 0.007368** | 0.008914** | 0.0003$^{ns}$ |
| Error | 49 | 3634 | 0.0033 | 0.002451 | 0.002098 | 0.002337 | 0.0002 |
| Min. | | 103.4 | 0.61 | 0.52 | 0.48 | 0.35 | 0.11 |
| Max. | | 316.9 | 0.84 | 0.80 | 0.74 | 0.66 | 0.18 |
| Mean | | 202.2 | 0.77 | 0.70 | 0.64 | 0.52 | 0.15 |
| CV (%) | | 24.9 | 6.7 | 8.5 | 9.5 | 12.8 | 8.4 |

SOV=Source of variation, NDVI BT=Booting, NDVI HD=Heading, NDVI AN=Anthesis, ND GF=Grain filling, NDVI=MT=Maturity.

value continued in similar trend when the plants reached grain filling stage ranging from 0.27 to 0.51 and 0.35 to 0.66 in sandy clay and clay vertisols, respectively.

NDVI recorded at different growth stages in two soil textures are illustrated in Figure 1. NDVI value reached a maximum prior to reproductive stages, and a slight decreasing tendency was observed at heading and further slight reduction at anthesis. The decreasing trend

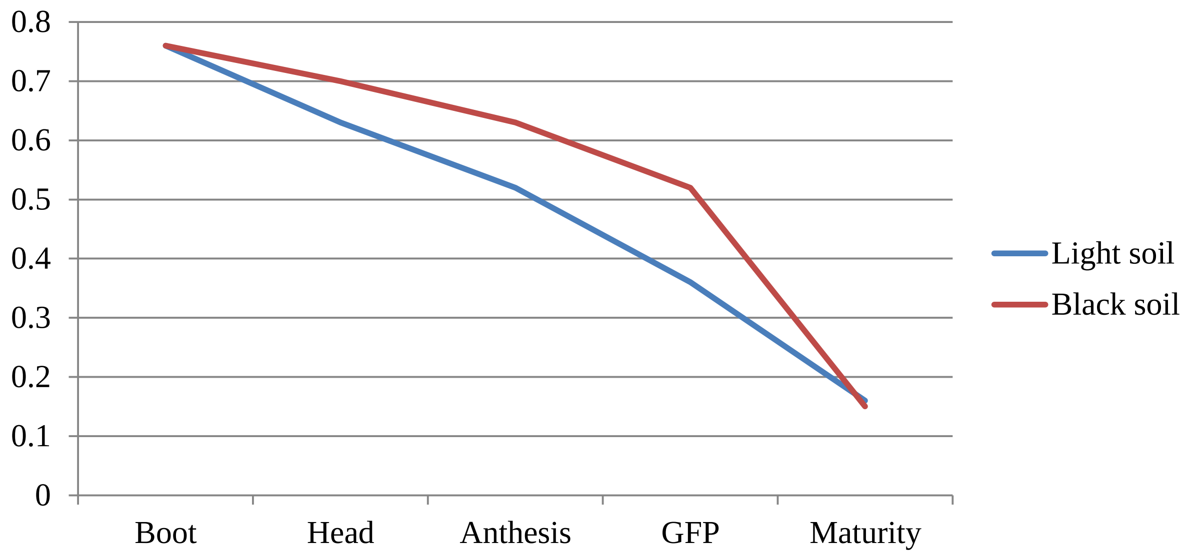


**Figure 1.** NDVI recorded at different growth stages for 64 durum wheat genotypes tested at Debre-Zeit sandy clay (light) and clay soils (black), 2016.

**Table 6.** Correlation on above diagonal (clay) and below diagonal (sandy clay).

| Traits | Grain yield | NDVI Booting | NDVI Heading | NDVI Anthesis | NDVI Grain filling | NDVI Maturity |
|---|---|---|---|---|---|---|
| Grain yield | | 0.37** | 0.28$^{ns}$ | 0.33** | 0.37** | 0.013$^{ns}$ |
| NDVI Booting | 0.37** | | 0.81** | 0.71** | 0.59** | 0.013$^{ns}$ |
| NDVI Heading | 0.39** | 0.88** | | 0.85** | 0.74** | 0.25$^{ns}$ |
| NDVI Anthesis | 0.41** | 0.80** | 0.94** | | 0.78** | 0.25* |
| NDVI grainfiling | 0.42** | 0.67** | 0.85** | 0.89** | | 0.30* |
| NDVI Maturity | 0.19$^{ns}$ | 0.41** | 0.51** | 0.61** | 0.59** | |

****=** Significant at 0.01, ns=non-significant.

in NDVI values was similar and sharp from grain filling stage where maximum variation between genotypes in NDVI scores was observed (Syeda et al., 2014). A soil variation on the values of NDVI was minimized at the time when genotypes reached physiological maturity.

## Correlation analysis

Correlation of NDVI traits with performance traits with yield at sandy clay and clay are presented in Table 6. The correlations were weaker (0.33-0.37) in clay soils which were less favorable for grain yield compared to sandy clay soils (0.37-0.42). The association was medium to high strength indicating that there is a significant relationship between NDVI values and the yield. The correlation was smallest at booting stage, increased at heading and anthesis and reached maximum during grain filling stage in sandy clay soil. In clay soil, the correlation was small and non-significant at heading, became significant with a slight strength at anthesis, and had relatively strong association at grain filling stage. It also clearly showed that NDVI scores highly significantly and consistently associated with yield were at grain filling stage in both soil environments, indicating that early selection of better yielding genotypes of wheat under terminal moisture can be identified. Similar finding was reported by Son et al. (2014) that grain filling stages are the right stage to get maximum variability and association with yield could be obtained. NDVI at maturity showed a non-significant and very weak correlation under both soil textures. This could be due to the severity of moisture stress which resulted in the reduction of the NDVI values associated to loosing leaf green pigment, yellowing and presence of low variation between genotypes at maturity in staying green trait. Mean NDVI values generally reached peak at booting; however, values during grain filling period were found to be the most correlated to the final grain yield in both soils, suggesting that it is the right stage for making earlier selections and estimating grain yield. Similar studies on NDVI suggested that grain filling stages display the maximum potentials for estimating yield (Spitko et al., 2016; Shanahan et al., 2001). Similarly, Nieves et al. (2000) indicated that under rain-fed conditions, the spectral reflectance indices measured at any crop stage were positively correlated ($P < 0.05$) with yield.

## Conclusion

The results of the study showed that the durum wheat genotypes varied significantly based on NDVI scores from booting to grain stages at both sandy clay and clay soil types but showed limitation on differentiation of the genotypes at physiological maturity. The results also revealed that normalized difference vegetation index (NDVI) is significantly correlated with grain yield under stress conditions. The grain filling stage was found to be the most appropriate stage to evaluate the genotypes under sandy clay and clay soils using NDVI as a screening tool. Although the correlation values between grain yield and NDVI records at different stages were relatively very strong, it is evident that integrating NDVI in the process will improve the rate of genetic progress and better complement the breeding process or screening of genotypes under drought. NDVI allowed better yielding lines to be identified; for instance, the genotypes 29, 30, 31, 21 and 16 were among the top yielding lines and showed consistently high NDVI values at different growth stages in both types of soils.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors thank the Ethiopian Institute of Agricultural Research (EIAR), Agricultural Growth Program II, (AGP II) and International Center for Agricultural Research Institute (ICARDA) for providing technical and financial supports for the execution of the field experiment. The authors also appreciate the support provided by Wondo-Genet Research Center and Debre-Zeit Research Center. Research and technical staff members of the crop research process of Debre-Zeit Research Center are highly acknowledged for assisting us on field activities.

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Vol. 16(1), pp. 8-21, January 2022
DOI: 10.5897/AJPS2021.2202
Article Number: 9BAA7FC68590
ISSN 1996-0824

http://www.academicjournals.org/AJPS

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African Journal of Plant Science

*Review*

# Current state of knowledge on the potential and production of *Cucurbita moschata* (pumpkin) in Africa: A review

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Received 27 October, 2021; Accepted 4 January, 2022

**Pumpkin has high nutritional value essential for food security. Despite many benefits, it still considered an orphan crop in Africa. Very little information is available on the potential and production of pumpkin in Africa due to neglect by researchers and improvement program. Classical research, both theoretical and empirical, was used to conduct a systematic review of the various result trends obtained by researchers in relation to the topic. Using Google Scholar, relevant literature was selected, analyzed and summarized. In Africa, the fruit, seeds and leaves of the pumpkin is consumed. This dietary diversity of pumpkin could contribute to the improvement of people's livelihoods. Countries such as Morocco, South Africa and Tunisia are making considerable profits from the export of pumpkin. However, its production is very low because its potential is not fully exploited. In this context, research and development strategies must be put in place so that pumpkin becomes part of the African diet. The diversity, origins and distribution, utilization patterns, relative importance, production and bottlenecks of pumpkin in Africa are reviewed. These results can be used as a basis for further research on yield improvement and pest management.**

**Key words:** Africa, bottlenecks, food security, orphan crops, pumpkin.

## INTRODUCTION

In 2019, global production of *Cucurbita* species (*Cucurbita moschata*, *Cucurbita maxima*, *Cucurbita pepo*) was estimated at 22,900,826 mt (FAOSTAT, 2019). According to the same source, African production is estimated at 2,793,530 mt. China (8,427,676 mt), India (5,655,994 mt), Ukraine (1,346,160 mt), and Russia (1,195,611 mt) are the largest global producers while Algeria (420,135 mt), Egypt (406,778 mt), Malawi (368,025 mt) and South Africa (270,486 mt) hold the largest production in Africa (FAOSTAT, 2019). Thus, pumpkin production in Africa is very low when compared with other continents, there is need to popularize this underutilized crop but potentially rich in nutrients in order to feed the growing population in a sustainable manner.

The consumption of plant-based foods has increased in recent years, due to public awareness of their benefits. Several epidemiological studies have shown that such a diet significantly reduces degenerative diseases such as

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cardiovascular events and some types of cancer (Adebayo et al., 2013). In traditional medicine, pumpkin is being used to cure the following diseases: hyperglycemia in diminishing the blood glucose concentration, hepatitis, macular dystrophy, abdominal cramps and distension due to intestinal worms, diabetes, hypertension, cancer, immunomodulation, bacterial and microbial infections, hyperon, hypercholesterolemia, intestinal parasites, digestive parasites, inflammation, obesity, and analgesic diseases (Chen, 2005; Yadav et al., 2010, Adam et al., 2011). Moreover, traditionally, it helps in increasing fertility immune system, eyesight, tackling convulsion, and promoting heart and skin health (Rahman et al., 2019; Hosen et al., 2021). Pumpkin is generally grown for its fruit and sometimes for its oil seeds (Fu et al., 2006). It is a low-calorie vegetable that fulfills many dietary requirements (PROTA, 2018). González et al. (2001) reported that pumpkin is an important source of vitamin A (4 ± 20 mg / g). This abundance of pumpkin in nutrients will be greatly beneficial for pre-school children (FAO/WHO, 2007). It is in this context that the works of Mbogne et al. (2015) in Cameroon have shown that pumpkin can thus play an important role in the fight against vitamin A, deficiency which affects more than 250 million children under the age of five worldwide. Pumpkin is a good source of ascorbic acid (22.9 mg/100 g) and inhibits the development of degenerative diseases such as cancer, diabetes, cardiovascular and neurological diseases (Roura et al., 2007).

Despite its dietary and economic advantages, pumpkin is not efficiently exploited and valorized in Africa. In Africa, production is still lower than that of China and India and almost the same with Ukraine and Russia. There is a need to value *C. moschata* as a source of nutrients to combat hunger and malnutrition and to boost its production in Africa through research and along the production of high added value products. Traditional crops are insufficient to feed the growing population in Africa, thus complementary underutilized food sources like *C. moschata* could be an important addition to the African diet. African researchers and improvement programs can no longer continue to ignore this valuable crop.

Aruah et al. (2010) conducted a study on the agro-morphological variations of local accessions of *Cucurbita* in Nigeria. The floral biology and breeding systems of *C. moschata* varieties in Nigeria were studied by Agbagwa et al. (2007). Kiramana and Isutsa (2017) conducted a detailed study on the quality characteristics of pumpkin in Kenya. Pumpkin was considered in the general vegetable census in Benin (Achigan-Dako et al., 2010). But no in-depth study has been conducted on *C. moschata* in Benin. The objective of this review was to (i) synthesize the most important information on morphological, agronomic, nutritional, ethnobotanical and economic traits of pumpkin; and (ii) elucidate the diversity, origins and distribution, utilization patterns, relative importance, production and bottlenecks of pumpkin in Africa.

## METHODOLOGY

The relevant literatures were selected from Google Scholars and then analyzed and summarized. The readings of those literatures gave us enough crossed views allowing to substantiate our remarks in a mega-analysis. A systematic review was used to achieve the goals of the paper, which was fundamentally based on classy research from both theoretical and empirical discoveries. The key results generated from update literature and deductive logical reasoning significantly contributed to understanding the crucial role that farmers play in the management and exploitation of the diversity of the *Cucurbita* spp. in Africa. The organization of this diversity with a viewpoint of varietal improvement and for future perspective in terms of research and policies making is important.

## BOTANY AND KNOWLEDGE OF THE PUMPKIN (*C. moschata*)

### Origin, domestication and geographic distribution of the species

All species of *Cucurbita* are native to the Americas (OECD, 2016). According to Jeffrey (1990), America is the center of origin of the different species of *Cucurbita*. *C. moschata* is native to North America (Mexico).

*C. moschata* was domesticated in Colombia (Whitaker and Davis, 1962). There are divergent opinions on the precise area where domestication probably occurred. Scientific studies on the natural distribution and domestication of *C. moschata* have been conducted by Merrick (1990) and Whitaker (1974). It was found that *C. moschata* had undergone two domestications (Mexico and the northern South America). These assertions were supported by linguistic evidence (Lira et al., 1995; Robinson and Decker-Walters, 1997). After Europe, *C. moschata* adapted to different ecological conditions across the globe (OECD, 2016). It is the most heat tolerant and well-known *Cucurbita* spp. in tropical Africa (PROTA, 2018).

### Taxonomy

Cucurbitales, Cucurbitaceae and Cucurbitoideae are respectively the order, the family and the subfamily of the genus *Cucurbita* (Jeffrey, 1990). It is distantly related to other genus in the family Cucurbitaceae (OECD, 2016). It is considered a different genus with 20 to 27 species (Cutler and Whitaker, 1968; Esquinas-Alcazar and Gulick, 1983). The genus *Cucurbita* is divided into two groups considering the ecological characteristics and life cycle length of the different cultivated species (OECD, 2016). Xerophytic species are perennial plants adapted to drought conditions with tuberous storage roots. Mesophytic species are determinate (annual) or indeterminate (perennial) plants adapted to humid climates, short-lived with fibrous roots. The genus *Cucurbita* includes 18 species among which 5 species are the most cultivated in the world. They are *Cucurbita argyrosperma, Cucurbita ficifolia, Cucurbita maxima, C. moschata* and *C. pepo*. These five species belong to the group of mesophytic species. Many names and grouping systems of which these species have been the subject are due to the morphological variation of the fruits and seeds (Table 1).

Despite its importance in many parts of the world in general and particularly in Africa, fewer scientific studies to elucidate the taxonomy of *C. moschata* have been conducted (OECD, 2016). The different relationships between 31 genotypes of landraces obtained in Malawi and Zambia were studied using random amplified polymorphic DNA analysis (Gwanama et al., 2000). It revealed that *C. argyrosperma* is the wild ancestor of *C. moschata.*

## Morphological characteristics

*C. moschata* is an annual herbaceous plant, very branched, creeping or climbing by lateral tendrils with 3 to 4 branches. The stems are angular with obtuse angle, very running, pubescent at the beginning and often rooting at the tendrils. These leaves are green or green mottled with white, they are alternate without stipules. The length of the petiole varies from 9 to 24 cm. The leaf blade has a broadly oval outline with 5 to 7 shallowly lobed palms of 10 to 35 cm in diameter. It has a toothed edge, soft hairs with sometimes white spots disappearing at senescence and 3 veins starting from the base.

The pumpkin is an allogamous plant (Lira et al., 1995; Whitaker and Robinson, 1986). They grow in the axils of the leaves (Figure 1). They have a color that varies between lemon yellow and dark orange. The length of the sepals ranges from 1 to 3 cm, these sepals are free. The corolla is campanulate with widely spread lobes. The lengths of the pedicels of the male flowers extend up to 16 cm. They are 3 staminate with free filaments and the anther is usually supported by a long twisted organ. The female flowers have a short pedicel (up to 3.5 cm). Their ovaries are inferior, ellipsoid with a thick style and 3 stigmas. The fruit is a large berry with a multiform (globular, cylindrical and ovoid). It weighs up to 10 kg. The fruits are covered with green spots and gray streaks. The flesh of the fruit varies from yellow to orange. The fruits have many seeds. The fruit stalk is angular with five ribs clearly widened at the apex.

The seeds are obovoid and flattened. The length and width of the seeds vary between 1-2 and 0.5-1 cm, respectively. The color of the seeds can be white or tan or sometimes dark. The surface of the seeds is smooth or a little rough. The seedlings have an epigeous germination. The cotyledons have an elliptical shape with a length of 2 to 4 cm. Despite these morphological characters, it is often very difficult to differentiate *C. moschata* from *C. maxima*. Differences in fruit peduncle, stems and leaves are the best indicators for easy differentiation (Table 2).

## Reproduction

*Cucurbita* spp. possess male and female reproductive flower organs in one single plant, thus they are monoecious plants (Lira et al., 1995; Whitaker and Robinson, 1986). Flowering of *Cucurbita* spp. is asynchronous, meaning male flowers appear well before female flowers (OECD, 2016). The near-synchronization at anthesis of both sexes is due to the early development of female flowers (Janick and Paull, 2008). Their lifespan is half a day (Nepi and Pacini, 1993). According to the same authors, the viability of pollen in a male flower decreases with time.

Cross-pollination of *Cucurbita* spp. is favored by both their monoecious natures and the size of the male flowers than the female flowers on the same plant (OECD, 2016). The proportion of male and female organs on a plant varies according to abiotic factors (Janick and Paull, 2008). This variation is due to temperature and light (Whitaker and Davis, 1962). *Cucurbita* pollen grains are large (80 to 150 μm in diameter), sticky and well adapted to transport by insects (OECD, 2016). For this reason, pollination is not carried out by wind in *Cucurbita* spp. *Apis mellifera* are the pollinators of these flowers (Canto-Aguilar and Parra-Tabla, 2000). A very large number of live pollen grains (500-1000) on the stigma of the female flower will allow for proper fruit development (Stephenson et al., 1988; Vidal et al., 2010). The flowering constitutes the favorable period or the ovules are fertile (OECD, 2016). In the process of pollinating female flowers, bees are guided by the olfactory signals of some species and probably also by visual or auditory sensors (OECD, 2016). According to these authors, nectar is collected by pollinators from female flowers, but pollen and nectar are collected from male flowers. The pollen adheres to the body of the bee when it visits a male flower in search of nectar. This pollen is then passed on to the stigmas which are covered with a somewhat sticky substance that allows the pollen to attach itself when visiting the female flowers (Zomlefer, 1994). Each pollen grain on the sigma of the female reproductive organ sprouts and a tiny (almost microscopic) rootlet develops, moves down the pistil, reaches the ovary of the flower which is then fertilized (PROTA, 2018).

**Table 1.** Diversity of species within the genus *Cucurbita.*

| Scientific name | Origin | Synonyms | Utilizations |
|---|---|---|---|
| *Cucurbita andreana* Naudin | Northeast Argentina, Northwest Argentina, Bolivia, Uruguay | *Cucurbita maxima* subsp. andréna (Naudin) Filov | Wild species |
| *Cucurbita argyrosperma* C. Huber | El Salvador, Guatemala, Gulf of Mexico, Northeast Mexico, Northwest Mexico, Southeast Mexico, Southwest Mexico, Nicaragua | *Cucurbita argyrosperma* var. callicarpa Merrick & DMBates, *Cucurbita argyrosperma* var. palmeri (LHBailey) Merrick & DMBates | Food, Medicinal |
| *Cucurbita cordata* S.Watson | Northwest Mexico | - | Wild species |
| *Cucurbita cylindrata* LHBailey | Northwest Mexico | - | Wild species |
| *Cucurbita digitata* A.Gray | Arizona, California, Northeast Mexico, Northwest Mexico, New Mexico, Texas | - | Wild species |
| *Cucurbita ecuadorensis* Coutelier & Whitaker | Ecuador, Peru | - | Wild species |
| *Cucurbita ficifolia* Bouché | Bolivia, Peru | *Cucurbita mexicaine* Dammann, *Pepo ficifolia* | Wild species |
| *Cucurbita foetidissima* Kunth | Arizona, Arkansas, California, Colorado, Iowa, Kansas, Central Mexico, Northeast Mexico, Northwest Mexico, Southwest Mexico, Missouri, Nebraska, Nevada, New Mexico, Oklahoma, Texas, Utah, Wyoming | *Cucumis foetidissimus* Hemsl., *Cucumis perennis* E. James | Wild species |
| *Cucurbita galeottii* Cogn. | Southeast Mexico | - | Wild species |
| *Cucurbita lundelliana* LHBailey | Belize, Guatemala, Southeast Mexico, Nicaragua | - | Wild species |
| *Cucurbita maxima* Duchesne | Northeast Argentina, Northwest Argentina, Bolivia | *Cucumis rapallito* , *Cucurbita farinae* Mozz. Ez Naudin, *Cucurbita maxima* var. Triloba Milan | Medicinal, Food, Cosmetics |
| *Cucurbita melopepo* L. | Alabama, Arkansas, Kentucky, Louisiana, Northeast Mexico, Mississippi, Missouri, Oklahoma, Texas | *Cucurbita ovifera* L., *Cucurbita pepo* convar. Ovifera (L.) Alef. | Food, Medicinal |
| *Cucurbita moschata* Duchesne | Belize, Guatemala, Central Mexico, Gulf of Mexico, Northeast Mexico, Southeast Mexico, Southwest Mexico | *Cucurbita macrocarpa* Gasp., *Cucurbita moschata* var. claviforme Harz, *Cucurbita moschata* var. colombienne Zhit. | Food, Medicinal |
| *Cucurbita okeechobeensis* (Petit) LHBailey | Dominican Republic, Florida, Central Mexico, Gulf of Mexico, Northeast Mexico, Southeast Mexico, Southwest Mexico | *Pepo okeechobeensis* Petit | Wild species |

**Table 1**. Contd.

| | | | |
|---|---|---|---|
| *Cucurbita palmata S.* Watson | Arizona, California, Northwest Mexico, Nevada, Utah | *Cucurbita californica* Toee. ex S. Watson | Wild species |
| Cucurbita pedatifolia LHBailey | Central Mexico, Gulf Mexico, Northeast Mexico, Southwest Mexico | *Cucurbita moorei* LHBailey | Wild species |
| *Cucurbita pepo* L. | Mexico Central, Mexico Gulf, Mexico Northeast, Mexico Northwest, Mexico Southeast, Mexico Southwest | *Cucurbita oblonga* Link, *Cucurbita pepo* subvar. alba Harz, *Cucurbita pepo* var. americana Zhit. | Food, ornamental, medicinal |
| *Cucurbita radicans* Naudin | Central Mexico, Northeast Mexico, Southwest Mexico | *Cucurbita gracilio* LHBailey | Wild species |
| *Cucurbita* × *scabridifolia* LHBailey | Gulf of Mexico, Northeast Mexico | - | Wild species |

- : No synonyms.
Source: KEW (2021).

After pollination, the fruit evolves from the mature ovary resulting from fertilization between the ovum and the spermatozoon, and the zygote becomes the seed in the ovary. The shape of the mature fruit depends on the shape of the ovary. The pulp around the seeds comes from the inner parts of the ovary (mesocarp and endocarp) (OECD, 2016). There is no means of asexual reproduction either by cuttings or stolons or budding in *Cucurbita* spp. level (OECD, 2016).

## Genetic diversity

### *Diversity inventor*

The chromosome number of *C. moschata* is 2n=2x=40 (OECD, 2016). The chromosomes are small and difficult to differentiate (Weeden, 1984). This complicates the description of their morphologies. Annual *Cucurbita* spp. evolved from perennial species (Wilson et al., 1992). Sanjur et al. (2002) and Wilson et al. (1992) suggested that *C. argyrosperma* is the wild ancestor of *C. moschata* (cultivated species).

### *Center of diversity and biotechnology developments*

*Cucurbita* spp. are well represented in the Cucurbitaceae genetic resource collections of several institutions around the world (PROTA, 2018). The National Seed Storage Laboratory (NSSL) in Fort Collins, Colorado, USA and the Vavilov Institute (VIR) in St. Petersburg, Russia, maintains substantial core collections. Large collections of *C. moschata* are conserved at the NBPGR genebank in New Delhi (India), NPGRL in Los Baños (Philippines), NIAS in Ibaraki (Japan), INIA in Celaya (Mexico), and CATIE in Turrialba (Costa Rica). Insubstantial attention has been paid to African landraces. *C. moschata* is one of the species for which the Southern African Developing Countries Plant Genetic Resources Center (SPGRC) in Lusaka, Zambia, is responsible. The introduction of improved cultivars threatens the disappearance of old landraces and the collection of plant genetic resources of these African landraces must be a priority.

The different cultivated *Cucurbita* spp. play a primary role in the food and nutritional security of the population (OECD, 2016). However, these species are subject to viral diseases that can cause considerable economic losses (Provvidenti, 1990). Insect vector control is the key means of controlling these diseases, but not without limitations (OECD, 2016). The use of advanced and biotechnological techniques has boosted and quickened the development of resistant varieties. Indeed, the insertion in the genome of the species of DNA sequences coding for the gene of the envelope protein of the virus will allow the protection of plants against these viruses (OECD, 2016).

### *Cucurbita production in the world*

The world production of fruits of *Cucurbita* including all species was about 22.900.826 t in 2019 (FAOSTAT, 2019). The main producing countries are: the People's Republic of China with 8.427.676 t, Ukraine with 1.346.160 t and Russia with 1.195.611 t (FAOSTAT, 2019).

According to FAOSTAT (2019), Algeria (420.135 mt),

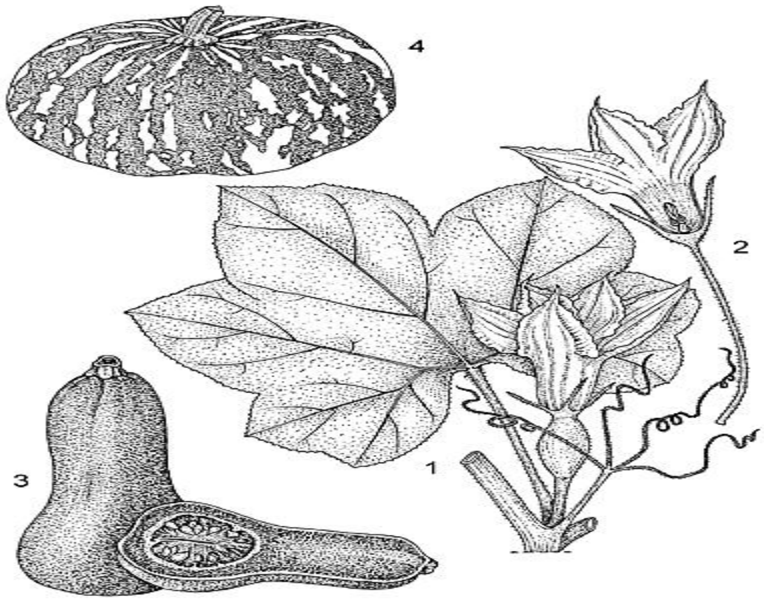


**Figure 1.** Morphological characteristics of a pumpkin plant. (1) Vines portion with female flower; (2) Male flower in longitudinal section; (3) Butternut variety; (4) Immature fruit.
Source: PROTA (2018).

**Table 2.** Distinctive morphological characteristics between winter squash and pumpkin.

| Characteristics | Winter squash | Pumpkin |
|---|---|---|
| Leaves | Soft and usually unlobed leaves | Tender and medium lobed leaves |
| Stems | Soft and rounded stems | Hard and slightly grooved stems |
| Peduncle | Soft, rounded peduncle, not widened at the apex | Peduncle hard, slightly angular and clearly widened at the apex |

Source: OECD (2016).

Egypt (406.778 mt) and Malawi (368.025 mt) are the major producers of pumpkin in Africa 2019. The major producers in West Africa are: Niger (192.581 mt), Mali (80.915 mt) and Côte d'Ivoire (19.316 mt).

## PHYSICOCHEMICAL, NUTRITIONAL AND ETHNOBOTANICAL COMPOSITIONS

### Physical properties, chemical compositions and nutritional values

The fruits of pumpkin range in weight from 0.59 to 8.75 kg, while fruit length and width range from 13.21 to 91.99 cm and 11.69 to 42.97 cm, respectively (Jacobo-Valenzuela et al., 2011). The thickness of the fruits varies from 1.80 to 6.95 cm. The pulp represents 71.75 to 86.06% of the fruit weight while the seeds represent 2.7 to 5.89% of the same weight.

*C. moschata* has a very important nutritional value for human health (Rakotovao, 1999). But this species of *Cucurbita* can express anti-nutritional compounds called cucurbitacins which are toxic and deadly to the humans (US Environmental Protection Agency, 1999). Carotenoids are essential group of biologically active elements with a wide range of health benefits (Kulczyński and Gramza-Michałowska, 2019a). The key carotenoids present in pumpkin are: zeaxanthin, lutein, β-carotene and retinol equivalent. According to the work of Norshazila et al. (2014), β-carotene is the dominant carotenoid in pumpkin. Lutein was the most predominant carotenoid in pumpkin fruits. Several internal and external factors could affect the concentrations of lutein and beta-carotene in pumpkin namely the type of variety, the growing conditions, the maturation period, and the storage time. In storage, lutein content rises while beta-carotene decline in pumpkin fruits (Jaswir et al., 2014). Indeed, beta-carotene concentration is also influenced by sun exposure, temperature, water availability, and the chemical composition of the soil. High beta-carotene

**Table 3.** Ascorbic acid, phenols, β-carotene content in winter squash and pumpkin (mg/100 g).

| Species | Vitamin C | Vitamin E | Total phenol | Total flavonoid | β-carotene |
|---|---|---|---|---|---|
| *C. moschata* | 7.9 ± 0.17 | 0.64 ± 0.05 | 453.72 ± 5.61 | 5.36 ± 0.07 | 0.58 ± 0.13 |
| *C. maxima* | 13.8 ± 0.23 | 1.74 ± 0.08 | 436.16 ± 2.89 | 8.23 ± 0.03 | 1.67 ± 0.06 |

Source: Zhou et al. (2017).

**Table 4.** Nutritional values of *C. moschata* 100 g.

| Parameter | Leaves | Fruits | Peeled seeds |
|---|---|---|---|
| Water (g) | 89.2 | 95.0 | 5.5 |
| Energy (Kcal) | 27 | 13 | 555 |
| Protein (g) | 4.0 | 0.7 | 23.4 |
| Fat (g) | 0.2 | 0.2 | 46.2 |
| Carbohydrates (g) | 4.4 | 2.2 | 21.5 |
| Fiber (g) | 2.4 | 1.0 | 2.2 |

Source: Holland et al. (1991).

levels are recorded during the early stages of fruit formation. The content of this compound decreases when the pumpkin fruits reach maturity (Kulczyński and Gramza-Michałowska, 2019a). The β-carotene content of fruits of the genus *Cucurbita* varies among species (Table 3). The dietary value of these species is mainly due to their organic (carbohydrate and protein) and especially mineral (calcium, phosphorus, and iron) contents (Rakotovao, 1999) (Table 4). The description of bioactive compounds in the pumpkin pulp is diverse and depends on the species and cultivar (Kulczyński and Gramza-Michałowska, 2019b).

Pumpkin is a vegetable used in human food which presents several derivatives (fruit, seeds and leaves). Pumpkin fruits from a nutritional point of view can be compared to tomato. Dietary diversification leads to better nutrition and food security. According to Dar and Sharma (2011), tomato fruits are rich in β-carotene (1.64 mg/100 g) and ascorbic acid (27.04 mg/100 g). The seeds of *Lagenaria siceraria* have high values of protein (28.2 g), lipids (49.8 g) while the seeds of *C. moschata* hold the high values of carbohydrates and fiber. The two-dimensional aspects of pumpkin could help improve people livelihoods.

## Socio-cultural aspect and different uses in rural areas

In North America, pumpkin is considered the fruit of health and is used in crops association with beans and corn (OECD, 2016). In Islam, pumpkin fruit in general represents the tree that God grew to give food and medicine to Jonas (PROTA, 2018). They further stated that the exegetes affirmed that the term "Yaqtin" refers to pumpkin. Some of them attribute tremendous advantages to these plants including the speed of its growth, the shade provided by its leaves due to their large size and flexibility, the nutritional quality of its fruits, the possibility of eating them cooked or raw, the usefulness of its peels and the fact that wolves do not dare get closer to it (PROTA, 2018). These authors further reported that the novelist Agatha Christie, in the humorous prologue to *The Labors of Hercules*, wanted to retire and devote herself to improving the taste of pumpkin.

*C. moschata* is used in food, animal feed and medicine. In human food, it constitutes vegetables whose leaves, fruits and seeds are consumed (PROTA, 2018). In Zimbabwe, "*Musatani*" landraces are used especially as leafy vegetables (Ndoro et al., 2007). According to these authors, during the rainy season the leafy vegetables of the pumpkin are consumed 3 to 4 times in a week. The different uses of the varieties of pumpkin in Benin (townships of Couffo and Borgou) are human consumption, sale, medicinal use and occultism (Ezin et al., 2021). According to these authors, the fruits of the pumpkin are used in the preparation of several recipes (simple sauce, egusi sauce and cooked ekpin) to satisfy the food and nutritional needs of the populations. Pumpkin seeds represent a nutritionally balanced source of protein (Vinayashree and Vasu, 2021). They contain all the essential amino acids except lysine and threonine. This abundance of pumpkin in nutrients will be greatly beneficial for pre-school children (FAO/WHO, 2007). The extracted oil from *C. maxima* seeds could be potentially utilized as a preservative and functional ingredient in foods and cosmetics (Montesano et al., 2018). The vines and fruits are used as fodder for domestic animals (Noguera, 2002). *Cucurbita* species are used in traditional medicine; as anthelmintic (Chou and Huangfu, 1960; Lozoya, 1994; Schabort, 1978); to treat prostate (Duke and Ayensu, 1985); as nerve tonic and to soothe burns, inflammation (Chopra et al., 1956); and as anti-hyperglycemic agent (Andrade-Cetto and Heinrich, 2005). In Benin, the leaves of "*Ekpin*", a variety of the pumpkin, are used to fight against fever and external hemorrhoids (Ezin et al., 2021). The content of active phytochemicals in Cucurbitaceae species must be further exploited for both preventive and therapeutic purposes (Salehi et al., 2019).

### Economic importance

In 2019, the main importing countries of fruits of the genus *Cucurbita,* all species combined in the world were: the United States of America (544.993 t), France (166.127 t) and Germany (108.909 t) (FAOSTAT, 2019). Additionally, the financial value of each of these imports was: US$438.532.000, US$164.113.000, and US$134.634.000, respectively. In terms of exports, Mexico (538.038 mt), Spain (449.193 mt) and New Zealand (84.626 mt) are the largest exporters in the world in 2019. The costs of these exports are US$424.439.000, US$ 405.414.000 and US$ 41.433.000, respectively.

According to FAOSTAT (2019), South Africa (1.710 mt), Libya (1.339 mt) and Namibia (481 mt) are the major importing countries of *Cucurbita* fruits in Africa. The costs of these importations are: US$601.000, US$652.000 and US$320.000, respectively. The main exporting countries in Africa are: Morocco (45.943 t), South Africa (18.909 t) and Tunisia (2.367 t) with export costs of: US$38.494.000, US$9.036.000 and US$1.306.000, respectively.

## ECOLOGICAL REQUIREMENTS

### Ecological conditions

The tropics are a favorable area for the cultivation of pumpkin (PROTA, 2018). According to these authors, it can be grown up to 1800 m altitude. It requires daytime temperatures above 20°C and nighttime temperatures above 14°C for good growth. It shows a slight response to short days. The production of pumpkin does not an abundance of water. *C. moschata* is fairly drought tolerant, but sensitive to frost and salinity. Excess moisture during the rainy season stimulates the development of fungal and bacterial diseases, causing leaf dieback, wilting and fruit rot. Pumpkin can be grown in almost any reasonably fertile, well-drained soil with a neutral to slightly acidic pH (5.5 - 6.8). Overall, the ecological requirements will depend on the soil, climatic conditions, pumpkin varieties, and management practices.

### Plant growth and development

In extensive cropping systems, pumpkin is produced in crop combinations with corn or sorghum (PROTA, 2018). This production occurs on termite mounds, garbage heaps, and livestock pens. Commercial production of improved cultivars requires pure cultivation. This production system is not well developed in African countries.

*C. moschata* is propagated by seed with a sowing spacing of 2 m × 2 m. The seed requirement at sowing is 2 to 7 kg/ha. High planting density provides soil coverage and faster weeds control. After sowing, there is the emergence of seedlings between 5 and 7 days. On fertile soil, the stems continue to grow as long as they can root at the nodes; they can exceed a length of 20 m. During the vegetative phase, for an optimal growth, the recommended fertilizer applications are: 50-100 kg/ha of N, 20-40 kg/ha of P and 40-80 kg/ha of K. Irrigation should be applied in dry conditions (50 mm/week). Sometimes plants are spiked to control growth and promote branching. Flowering is more or less continuous and starts 35 to 60 days after seedling emergence. Mendlinger et al. (1992) stated that the collected accessions of pumpkin reached 50% flowering in the range of 57.3 to 88.3 days. In Nigeria, according to Agbagwa et al. (2007), flowering occurred 56 days after *C. moschata* sowing. However, the different variations observed in days to 50% flowering could be mainly due to intra-species variability. The ratio of male to female flowers is approximately 20:1 (PROTA, 2018). According Agbagwa et al. (2007), the ratio of male to female flowers is 9:1. The highest and lowest male to female flower ratio in Bangladesh was 12.11:4.08 and 10.24:3.27, respectively (Islam et al., 2016). This ratio is influenced by environmental factors (temperature and day length) and chemical regulators (ethylene and gibberellin) (OECD, 2016). Male sex expression is favored by long days and high temperatures (PROTA, 2018). According to these authors, one to two fruits develop per vine. The fruit ripens 60-120 days after sowing. Based on agro-morphological evaluation of pumpkin genotypes in northern Bangladesh, fruit ripening occurred in the range of 103 to 123 days after sowing (Ahamed et al., 2011). Recommended good cultural practices call for mulching the soil, weeding, rouging, pest and disease control measures, wrapping the fruit in paper to protect it from fruit flies, and hand pollination to increase fruiting.

### Diseases and pests

*C. moschata* is attacked by many pathogens and pests. Downy mildew (*Pseudoperonospora cubensis*) often becomes a devastating disease under very high humidity (OECD, 2016). The lower leaf surface becomes covered with a light purplish layer and the leaf dies completely. Good cultural practices such as crop rotation, good drainage are an integral part of the various control methods for late blight. *Erysiphe cichoracearum* causes a disease known as powdery mildew that occurs when moisture is low (PROTA, 2018). Symptoms are usually

**Table 5.** Characteristics of pumpkin varieties.

| Specie | Varieties | Description | Average fruit weight (kg) |
|---|---|---|---|
| *C. moschata* | Seminole | Round, oblong or irregular shape. Green, buff, yellow or piebald hard rind. | 2.10 |
| | Dickinson | Variable shape, smooth, hard, buff colored hard rind. | 12.60 |
| | Waltham butternut | Long, curved or straight neck. Smooth and hard rind. | 2.72 |
| | Musquée of Provence | Very large fruit with very prominent ribs. | 17.40 |
| | F1 Sweetmax | Large fruited early maturing variety, producing around three fruits per plant with great internal colour and flavour. | 1.88 |
| | Courge de Côte d'Ivoire | Oblong blocky (cylindrical) shape. Green, buff, yellow or piebald hard rind. | 11.50 |
| | Rabat | Acorn-shaped fruit (heart-shaped) with a green color combined with yellow. The main color of the flesh is yellow. The leaves are marbled with white. | 13.73 |
| | Caravelle | Fruit in elongated form whose main color of the flesh is orange. | 9.30 |

seen first on older leaves. Infested leaves die, plants prematurely senesce by reducing photosynthesis and thus declining yield (Agrios, 2005). Alternaria (*Alternaria cucumerina*) is a fungal disease that defoliates and kills the plant within a few weeks (Blancard et al., 1994). Symptoms are represented by small, round, whitish necrotic spots. Leaves turn gray or yellow and dry out. Attacks of this disease can be limited by using healthy seed, disposing of crop residues, and rotating crops. *Didymella bryoniae* is a fungus that causes black rot or gum disease (Davis, 2008). Symptoms of this disease include fruit discoloration and branching wilt. The use of healthy seeds, preventive fungicide (mancozeb) and crop rotation are part of the control methods. Fusarium (*Fusarium oxysporum*) causes yellowing of leaves followed by wilting of the entire plant (OECD, 2016). The use of healthy seeds, elimination of crop residues, crop rotation and rational use of nitrogen fertilizers can control this pathogen. Anthracnose (*Colletotrichum lagenarium*) causes defoliation and lesions on the fruit (Bar-Nun and Mayer, 1990).

Many viruses have been reported on *C. moschata*. These include cucumber mosaic virus (CMV), papaya ring spot virus type W (PRSV-W), squash mosaic virus (SqMV) and watermelon mosaic virus (WMV-2) (OECD, 2016). Cucumber mosaic virus manifests as leaf yellowing, ring spots, stunting, and deformation of leaves, flowers, and fruit. Aphids, seeds, and weeds are the primary vectors of CMV (OECD, 2016). PRSV-W is transmitted through aphids. Leaves and plants become mottled and branching are stunted (Brunt, 1996). SqMV is transmitted non-persistently by several insects (Brunt, 1996); by seeds and mechanically (OECD, 2016). Symptoms of WMV-2 are stunted fruits and yellowing leaves. Plants stop producing marketable fruit one to two weeks after infection (OECD, 2016). To prevent the spread of virus diseases, control of the main vectors of these viruses (aphids, whiteflies, and thrips) is necessary (PROTA, 2018).

## CHARACTERISTICS OF THE VARIETIES

There are several varieties of pumpkin, only some varieties will be listed in this paper (Table 5).

### Harvest and post-harvest activity

Harvest is performed over a period of 2 to 6 months after planting (PROTA, 2018). Yield is highly dependent on species, variety, and cultural conditions. The fruit weight of *C. moschata* varies between 1 and 10 kg, respectively; the fruit yield is low under extensive cultivation (5 t/ha) (Whitaker and Davis, 1962). The use of improved cultivars can yield 30 t/ha, the average yield is 15 t/ha. The yield of leaves is 20 t/ha for a harvest period of 2 months. Excessive harvesting of young leaves significantly reduces fruit yields. Seed yield is variable and can reach up to 300 to 500 kg/ha (Sharma and Lal, 1998).

In Africa, the deficiency of micronutrients in the daily diets is leading to adulteration of food, malnutrition and nutrition insecurity and unsafety. Pumpkin is regarded as a reservoir of micronutrients but not sufficiently exploited owing to many factors such as the lack of knowledge of the food virtues of this vegetable by the consumers and the waste due to post-harvest losses. The leaves of pumpkin are highly perishable and the fruits cannot be stored for long periods. In this context, fermentation of pumpkin leaves seems to be essential vital processing method for increasing the shelf life of this vegetable

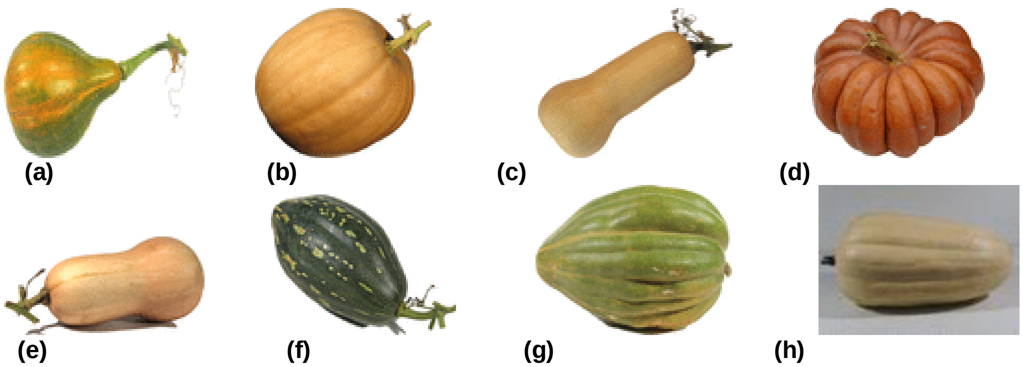


**Figure 2.** Eight varieties of *C. moschata*. (a) Seminole; (b) Dickinson; (c) Waltham butternut; (d) Musquée of Provence; (e) F1 Sweetmax; (f) Courge de Côte d'Ivoire; (g) Rabat; (h) Caravelle.
Source: Esquinas-Alcazar and Gulick (1983) and SFC (2016).

(Misci et al., 2021). According to the work of these authors, fermentation could help to preserve the leaves of *Cucurbita* spp. by preventing contamination by altering microorganisms and by enhancing the nutritional value of the final product. This method consists of tying the leaves in bundles and making them moist under a jute bag. The drying of the leaves constitutes a means of conservation. The dried leaves are stored in containers and used in times of shortage. This innovation packages will improve upon the food and nutritional security. Post-harvest preservation will allow the pumpkin leaf vegetable to be available for consumption. Its affordability will allow it to be accessible to different segments of the population. The fruits can be stored for long periods. The "Butternut" variety can be stored for at least one month and the large pumpkin for several months (Whitaker and Davis, 1962).

They further illustrated that storage is at 10 to 16°C and 70% humidity. In cold storage, cold damage occurs at temperatures below 10°C. Drying the flesh of the pumpkin is a preservation method for its later use in soups and stews (PROTA, 2018).

Seeds are removed after the fruit is eaten. These seeds can be used as planting materials or in human food. Seeds are sold shelled or unshelled (Souley et al., 2018). The different operations in order to obtain pumpkin powder are: sorting, sprinkling, hulling and grinding (Salifou et al., 2015). Manual hulling is tedious; mechanized hulling is now practiced in several countries including Nigeria and Sudan. Hulled seeds are more susceptible to storage pathogens, particularly *Aspergillus,* which release toxic aflatoxins in hot and humid conditions (PROTA, 2018).

## Processing and valorization

### *Inventory of processing products and derivatives*

*C. moschata* has been playing an important role in the food and nutritional security of rural communities since ancient times (Belkebla and Makhloufi, 2016). The purpose of processing is to add value to agricultural products and increase their post-harvest shelf lives. In the agri-food field, many pumpkin-based products and preparations are marketed as fruit jams, syrups (Nawirska et al., 2009). These authors also showed that pumpkin is also used as an additive in various food products. Pumpkin fruits are processed into soups, stews (Durante et al., 2014); juices and marinades (Aydin and Gocmen, 2015). According to Zargar et al. (2014), their pulps can be incorporated into chicken sausages for the purpose of enriching them with plant-based dietary fiber. A combination of pumpkin and apple leads to marmalade (Figure 2) (Rakotovao, 1999). Pumpkin seeds can be used as substitutes for Egussi (*Citrulus lanatus, L. siceraria*, and *Cucumeropsis edulus*) (PROTA, 2018). According to the work of Salifou et al. (2015), three derivative products are obtained from these seeds. These include pumpkin powder; pumpkin oil and fried pumpkin fritter (Figure 3).

## OPPORTUNITIES AND CHALLENGES FOR *C. moschata* IN AFRICA

### Opportunities

*C. moschata* is under the responsibility of the Southern African Developing Countries Plant Genetic Resources Center (SPGRC) based in Zambia (PROTA, 2018). Algeria, Egypt, Malawi, South Africa, Nigeria, Kenya, Cameroon, Congo and Niger are among the African countries that value pumpkin production. Studies addressing various issues related to production improvement precede the promotion of pumpkin. However, pumpkin is not included in Benin's agricultural policy despite being an extraordinary vegetable with the potential to be used as a medicinal as well as a nutritious multifunctional food. Pumpkin peels and flesh contain essential minerals as well as phytochemicals (β-carotene,

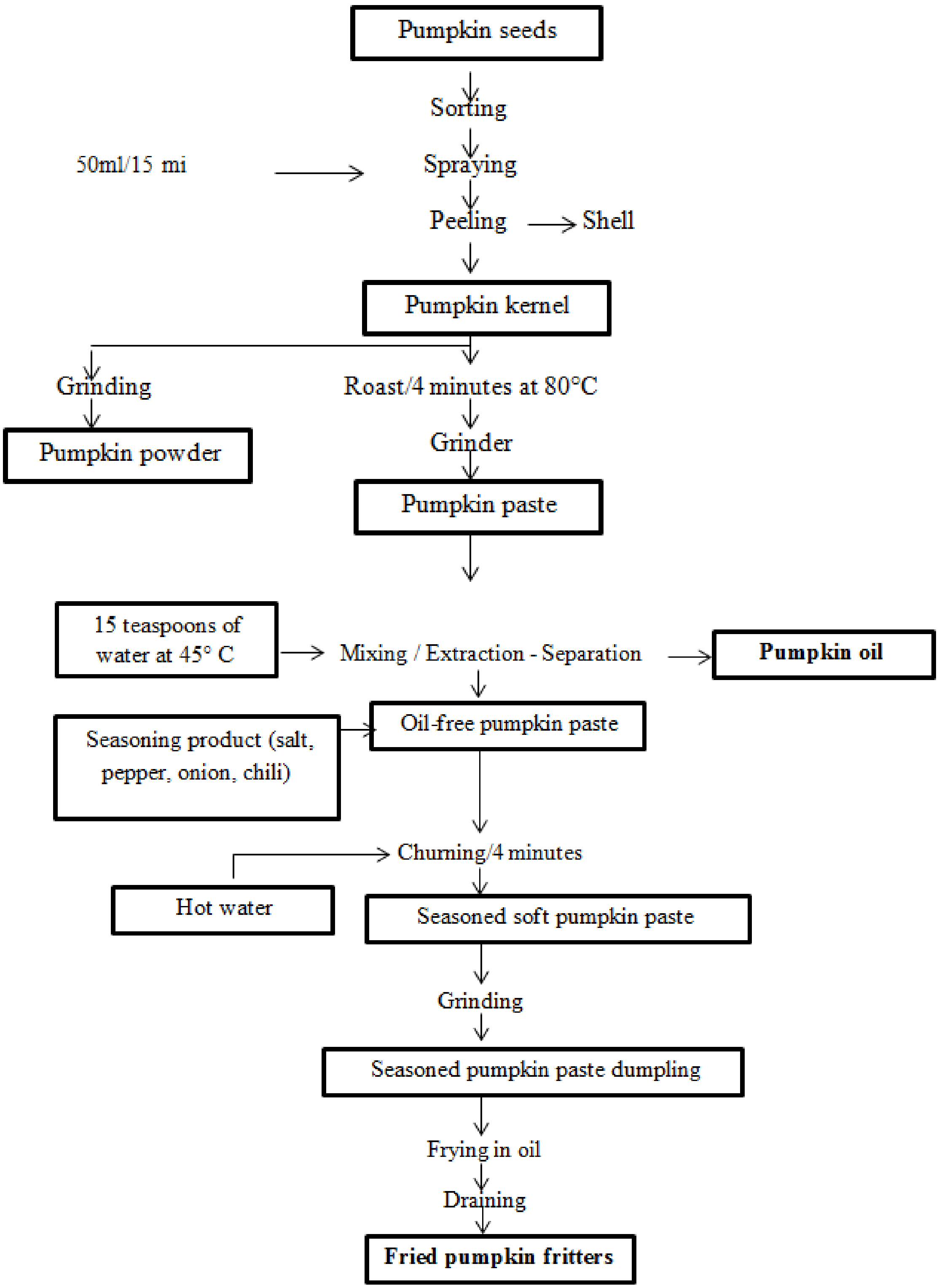


**Figure 3.** Diagram of the processing of pumpkin into fried pumpkin fritters in Benin.

total flavonoids, and total phenolic) that can help with antiaging and the immune system (Hosen et al., 2021).

The consumption of Pumpkin enhances vitamin A intake, fortifies diets, and diversifies foods by including animalderived foods (Buzigi et al., 2021).

According to the work of Du et al. (2011), *C. moschata* can be cultivated in different agro-ecological zones and presents a great morphological variability (color and shape of the fruit). The collection of south Africa and other African countries could be the starting point for future breeding programs in Africa, which could contribute to reduce hunger, malnutrition and generate income both in rural and urban areas for the producers and especially women (Ntuli et al., 2017). In Africa, the production of *C. moschata* is very low and is for local consumption (Andres, 2004). It is adapted to different abiotic conditions (climate and soil) (Gwanama et al., 2000). In many developing countries, indigenous foods, which are often more nutritious than modern foods traded on the world market, are neglected and forgotten (CDB, 2008). In a context of climate change and loss of biodiversity, pumpkin appears as a potential candidate for food security of populations. This choice is justified by its adaptability to several environmental conditions and by its richness in nutritive elements. Thanks to its different uses, the pumpkin creates a food diversity that contributes to a balanced and nutritious diet. Its production and transformation contribute to the creation of employment. In Niger in the Guidimouni basin, labor costs represent 6% of operational expenses on an area of 2500 $m^2$ (Souley et al., 2018). The various costs associated with importing and exporting pumpkin are an indicator of the availability of demand and supply in the market (FAOSTAT, 2019). In Niger, the price of 100 pumpkins varies from 60000 to 130000 FCFA depending on periods of abundance and shortage (Souley et al., 2018). On the Africa market, supply exceeds demand, as consumers are not aware of the nutritional and therapeutic virtues of pumpkin.

## Challenges

According to Zargar et al. (2014), a major challenge will be to increase agricultural production in the coming years so that food and nutritional security is a reality for the local population and to meet consumer demands for quality agricultural products. In this situation of health crisis, the effective use of pumpkin and its derivatives could contribute to food security; improve the income of producers and other links involved in the value chain. Among the challenges to be taken up for the promotion and valorization of the pumpkin in Africa are:

(1) The promotion of research and development addressing the issues of seed quality, production management, pests and diseases, weeds and soil fertility, varietal improvement rich in nutrients and vitamins to meet the needs of consumers,
(2) Establishing agronomic production systems to maximize productivity,
(3) Establishing production expansion strategies, efficient storage and processing technologies,
(4) Put in place different innovative farming systems and technological packages for the popularization of the benefits of pumpkin to producers and consumers,
(5) The establishment of a well-structured and developed value chain.
(6) Availability of genetically improved varieties
(7) Genetic erosion of some varieties
(8) Government policies to promote the crop through research funding
(9) Including it in African' diet and nutrition programs and policies
(10) Dire need to popularize the crop and its utilization at all levels

## CONCLUSION

Pumpkin is a nutrient-rich, high-yielding, low-cost vegetable. It can help to alleviate food and nutritional insecurity. The transformation processes make it possible to have pumpkin-based products with a good organoleptic and sensory quality and respecting the sanitary standards. It is a significant source of income for producers. But despite all these assets, it is still a marginalized crop in research and development programs and in the food habits of the populations. The immediate consequences of these actions are, on one hand, the absence of selection programs for yield, disease resistance and the implementation of processing technologies in the agri-food, medicinal and cosmetic fields. On the other hand, the risks of genetic erosion of traditional varieties of pumpkin. In this context, the richness of this species must be studied with the support of various ethnobotanical, agronomical and morphological identification tools. These results could contribute to understand not only the crucial role that farmers play in the management and exploitation of the diversity of these species, but also the organization of this diversity in a perspective of varietal improvement. Many challenges remain to be lifted in order to make pumpkin production profitable in Africa.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors sincerely thank Gazali SANNI, David CARRENA and Nelson VODOUNON for their scientific contributions during this study.

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