JOURNAL OF HORTICULTURE AND POSTHARVEST RESEARCH
2021, VOL. 4(4), 427-438

Journal of Horticulture and Postharvest Research

Journal homepage: www.jhpr.birjand.ac.ir

University of Birjand

Growth, development, maturation indices, proximate and mineral composition of moringa *(Moringa oleifera)*

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ARTICLE INFO

Original Article

Article history:
Received 28 April 2021
Revised 29 May 2021
Accepted 9 June 2021
Available online 12 August 2021

Keywords:
Growth
Maturity
Minerals
Moringa

DOI: 10.22077/jhpr.2021.4296.1205
P-ISSN: 2588-4883
E-ISSN: 2588-6169

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ABSTRACT

Purpose: *Moringa oleifera* is a multi-purpose plant. The growth curve would determine harvest date and maturity indices. Analysis of proximate and mineral constituents would highlight nutritional and health benefits. **Research methods**: Investigations were conducted on growth curve parameters, maturation indices, proximate and mineral compositions of moringa plant parts (*Moringa oleifera*) on four-year-old tress from 2016-2019. **Findings**: The growth curve depicted a single sigmoid shape. Pods harvested 25 days after flowering were immature (M1), with a light-green skin colour, firm, tender seeds, and light greenish-cream flesh and seeds. Pods attained horticultural maturity with optimum cooking quality 32 days (M2) post-anthesis with corresponding maturity indices being firm, light greenish-cream-flesh and well–formed seed. Dried partially senesced over-matured pods (M3), harvested after 51 days, had a light-brown dermal layer enclosing dark brown firm seeds with the highest fat and crude fiber being 200.3 g/kg and 314.5 g/kg. Green-tender seeds showed the highest crude protein content of 296.0 g/kg. Immature leaves (L1) had the highest dry matter content while stage 2 leaves had the highest ash content. Matured pods showed the highest moisture content. Mineral contents of stage 3 leaves (L3) consisted of magnesium (4255.6ppm) and calcium (32404.2 ppm), while stage 1 leaves had the most iron (147.0 ppm) and potassium (30210.0ppm). Leaves at stage 2 had the most sodium (2547.9 ppm) and boron (23.1 ppm). **Research limitations**: Limited cultivars. **Originality/Value**: Maturity indices on the growth curve confirmed the multi-purpose nature of the moringa plant and benefits to the food and health industries.

INTRODUCTION

Moringa oleifera is distinguished as one of the world's most versatile, nutritious multi-purpose plant (Bridgemohan et al., 2020). Grown throughout the tropics, various parts of the plant have substantial potential for improving the nutritional and health status of poor households to enhance food and nutrition security and could be utilized for food, forage, medicine, dye, and water purification (Palada & Chang, 2003; Arshad & Takacsne, 2020). Moringa plants would contribute to the fundamental elements' food security including food availability, accessibility, utilization and stability which are urgently required in view of the potential food crisis accelerated by the global COVID-19 pandemic (Asogwa et al., 2019; Bridgemohan et al., 2020). Moringa trees are drought resistant and plant parts are enriched in bioactive compounds that are necessary for the normal functioning of the body, alleviating some diseases and reducing the alarming incidence of malnutrition in many developing countries (Screeja et al., 2021).

While several studies are published on the proximate and mineral composition of various parts of the moringa plant (Arshad & Takacsne, 2020; Moyo et al., 2011; Oduro et al., 2008; Aborisade et al., 2017; Bamishaiye et al., 2011), investigations on the developmental profile to highlight the growth curve to identify the most suitable stage of maturity for cooking purposes, incorporation of effective postharvest treatments to extend the shelf life, sensitivity to low temperature storage and utilization of dried seeds for inclusion in value-added food products have received less attention. Quantitative analysis and verification of the proximate and mineral composition of leaves, flowers and matured pods are necessary to support previous studies in view of variables associated with several pre-harvest factors such as differences according to varieties, location, climatic conditions, and cultural practices. Therefore, further studies are warranted to fulfil information gaps and to supplement existing data on this plant that is currently advocated as a super food.

Accordingly, the objectives in this study were to determine the growth curve pattern from flowering to fruiting, to characterize maturity indices based on utilization of the moringa pods as well as to investigate the proximate and mineral composition of M2 pods and leaves, flowers and seeds at different stages of maturity.

MATERIALS AND METHODS

Three experiments were conducted, two of which involved laboratory investigations on the proximate and mineral compositions at the Professor Wilson Food Laboratory at the University of the West Indies, St. Augustine Campus, Trinidad. Prior to those two experiments, field studies were conducted on trees located in Central Trinidad to collect data on growth and development of moringa pods from flowering to pod maturity.

Experiment 1

This trial was conducted on established moringa trees located in Central Trinidad to investigate the growth and development of moringa pods from flowering to fruiting. Eight branches from 8 trees per branch were randomly selected and tagged at various stages of maturity from flowering until complete pod development. The diameter of the tree trunks varied between 42-45 cm when measured at 1.4-1.5 m above ground level. The tagging procedure involved selection of flowers at the proximal end of each branch. Each floral peduncle was tagged using laminated paper labelled in alphabetical order. In some instances,

where the ink-stained alphabetical letters were dissolved and eventually erased due to heavy rainfall and gusty winds, newly labelled tags were replaced with a numerical figure to distinguish emerging flowers from senesced flowers. Data from tagged flowers were recorded every two consecutive days up to the 51st day between 6 am to 8 am where the mean air temperature was recorded at 28^{0}C to 31^{0}C. Measurements of length (cm) and width (cm) of pods were taken throughout growth and development over 51 days using a Vernier calliper.

Experiment 2

This investigation was conducted to determine the proximate composition of moringa leaves, flowers, pods and seeds at different stages of maturity in the Professor Wilson Food Laboratory, University of the West Indies, St. Augustine campus. The study involved destructive sampling. Each moringa plant part selected at 3 stages of maturity consisting of leaves, flowers, pods, green and dried seeds were dried and ground to a fine powder separately using a mortar and pestle and labelled and stored at 5°C in air-tight containers prior to further analysis.

The proximate analyses (Table 1) of all the samples were determined. The moisture and ash contents were determined using the weight difference method. Fiber content was estimated from the loss in weight of the crucible and its content on ignition. Carbohydrates were determined when the sum of the percentages of moisture, ash, crude protein, ether extract and crude fiber were subtracted from 100. The nitrogen value which is the precursor for protein of a substance was determined by Kjeldahl method as described by Pearson (1976), involving digestions, distillation and finally titration of the samples. The nitrogen value was converted to protein by multiplying a factor of 6.25. All the proximate values were reported in g/kg (Horwitz & Latimer,2005).

Experiment 3

In order to determine the macro and micro-nutrient concentration, the moringa samples (leaves at 3 stages of maturity, flowers at 3 stages of maturity, matured pods, green tender seeds and dried seeds) were dried and subjected to grinding as described above. Clean and dried 100ml glass beakers were placed on an oven at 105^{0}C overnight and were cooled in the desiccator for 30 minutes. After the beakers were cooled, 5-5.5g of the various moringa parts samples were weighed and placed in the 100 ml glass beakers then left overnight in a 100^{0}C oven. Thereafter, beakers with the moringa samples were placed in the muffle furnace at 550^{0}C for 3-5 hours and then 8 hours to obtain white and carbon free ash. Thereafter, the ashes were filtered in a 50 ml volumetric flask and left to cool and transferred into 100 ml glass beakers, and dissolved with three sets of 5 ml HNO_3 one set at a time on a hot plate for 2-3 minutes. A glass rod was used to scribe the bottom of the beakers and filtered onto clean beakers. Samples were diluted with 1M HNO_3 to 50 ml and shaken for 20 seconds. After allowing samples to sit for 1 hour, it was then transferred to labelled 50 ml plastic bottles. These samples were then taken to Professor Nazeer Ahmad Laboratory, Department of Food Production, where the Atomic Absorption Spectroscopy (240FS AA) method was used. Phytonutrients that were investigated were potassium, magnesium, calcium, sodium and iron using the Flame Emission Absorption Spectrometry (FEAS) technique which determined in parts per million and boron was determined used the Graphite Tube Atomizer (GTA 120) technique in parts per billion. The phytochemical composition was done according to the methodology described in AOAC (1980) and by Horwitz and Latimer (2005). Readings were recorded for each macro and micro-element and calculated using the formula (1) hereunder:

$$\frac{[(C_S \times DF_S) - (C_B \times DF_B)] \times DV}{M_S.} \quad (1)$$

C= concentration (mg/L), S= sample, DF= dilution factor

Statistical analysis

Experiment 1: The experiment consisted of a complete randomized design (CRD) with eight branches from eight trees with each branch consisting of ten flowers. The data generated were subjected to analysis of variance (ANOVA) using SPSS program. Significant differences were assessed at 5% ($p \leq 0.05$) level of significance.

Experiments 2 and 3: The experiment consisted a complete randomized design with three replicates for leaves, flowers at three stages of maturity, matured pods, green and dried seeds. The data generated were subjected to analysis of variance (ANOVA) using SPSS program. Significant differences were assessed at 5% ($p \leq 0.05$) level of significance and the mean was separated using least significant difference (LSD) procedure.

RESULTS AND DISCUSSION

Experiment 1

Moringa pods had a single sigmoid shape growth curve based on dimensions of length and width (cm) and hereby illustrated in Fig 1. The single sigmoid shape curve for moringa pods obtained in this investigation is in support of findings for other commodities reported by (Erkan & Kader 2011; Kundan et al., 2006; Yahia 2014). Anthesis occurred 7 days after initiation of the floral primordia. Transformation of flowering into the first visible evidence of pods occurred after 14 days. Measurements of pods after fruit set were recorded after 25 days. Fruit set represented the transformation of the ovary to a rapidly growing young fruit which is initiated after successful pollination and fertilization (Din et al., 2019). Fruit set in moringa pods was 2 days postanthesis similar to studies published by Din et al. (2019) on 'Agua de Aranjuez' pear, but different to 'Hayward' kiwi fruit which occurred 1 day after anthesis (Vasilakakis et al., 1997).

This growth curve (Fig. 1) highlighted three stages of maturity of the *Moringa oleifera* pods. For maturity 1 (M1), which occurred 25 days postanthesis, the skin was light-green in colour whilst the inner flesh retained a white colour. Seed size was less than 0.2 cm in width and approximately 0.7 cm in length. Seeds from M2 were off-white in colour and the testa was light-green in colour. Maturity 2 (M2) pods were determined after 32 days postanthesis and characterized with a darker green colour on the external dermal layer and seeds were almost fully developed. Seed size was 1 cm width and 1.5 cm in length. Seeds were off-white in colour and the testa had a light-green colour whilst the flesh maintained the same cream-whitish colour. Maturity 3 (M3) occurred 51 days after anthesis, 26 days after M1 and 19 days after M2 (Fig. 1). M3 also showed visible signs of the initiation of senescence with vertical light-brown coloured strips on the outer layer of the moringa pods and dark brown over-matured seeds which were 2 cm in width and 1.5 cm in length. Throughout senescence, moringa seeds turned black in colour while the internal flesh of the pod was cream to light brown in colour. The flesh of the moringa pod became fragile as senescence progressed. M3 pods were 46.7 cm in length and 3 cm in width. Two weeks thereafter, the seeds changed from green to dark brown.

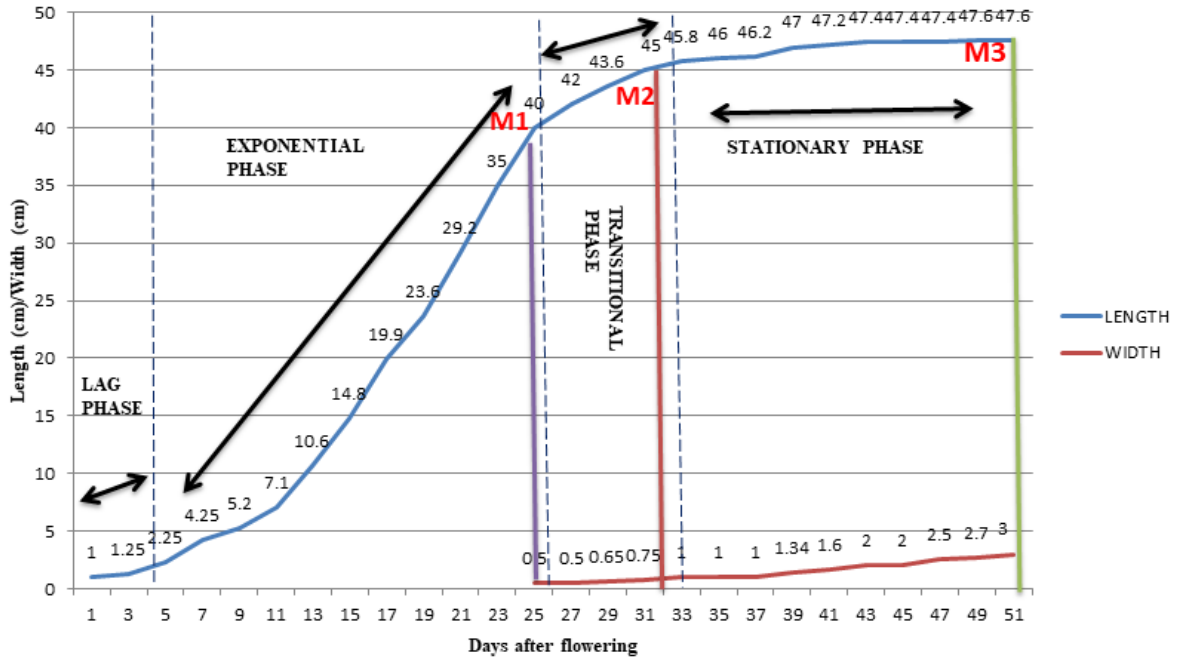

Fig. 1. Growth and development curve of moringa podsz.
[z] LSD $_{(0.05)}$ = 18.2 cm (pod length); LSD $_{(0.05)}$ = 0.9cm (pod width).

The growth curve shown in Fig. 1 also depicted various phases of a typical sigmoid shape growth curve. It consisted of the lag phase (A) where the fruit cells were metabolically active and increased only in cell size slowly since cell division was taking place gradually. In this study, the lag phase occurred after 1-4 days after flowering. This was followed by the log phase (B) or the exponential phase representing the time of exponential growth, shown by that part of the growth curve that is a straight line from 5th-26th day representing 22 days (Fig. 1). The next phase thereafter hereby referred to as the stationary phase occurred from 33th to the 51st day. These findings need to be expanded to include recent advances and debates on the impact of climate change and factored in pre-harvest factors associated with growth and development phases as well as postharvest quality parameters and articulated in subsequent investigations of the moringa plant.

The time intervals recorded for the different phases of the moringa pod (Fig. 1) were different to that reported by (Kundan et al., 2006) in their study with passion fruit. Thus, while in moringa the lag phase occurred from days 1-4 with recorded length of 0.02 cm, the lag phase investigated by (Kundan et al., 2006) was between days 1-7 but their measurements focussed on diameter. An increase in fruit growth occurred in the exponential phase (Fig. 1) from day 5-16 with the length ranging from 0.05cm to 45cm and width of 0.5cm-0.75cm which corresponded with moringa pods indicative of attaining M1 (Fig. 1). In the purple passion fruit investigation (Kundan et al., 2006), a sharp increase in fruit growth occurred in the exponential phase but over a substantially prolonged time interval of 40 days with a diameter of 1 -2 cm. This was followed by the transitional phase which occurred 7 days after the exponential phase and the steady phase at the 77th day after the beginning of fruit development.

Experiment 2

In this investigation data were recorded on the proximate composition of moringa leaves and flowers at three stages of maturity as well as on the mature pods and green and dried seeds.

The significant decline in fat content as leaf maturity advanced from L1, L2 and L3, was consistent for flowers at maturity stages FI, F2 and F3 (Table 1). Matured pods (MP) had the lowest fat content (8.0g/kg). The fat contents of green seeds (GS) were 114.3g/kg which was significantly lower than that obtained for dried seeds (DS) (200.3g/kg) (Table 1). Several authors have reported extensively on parts of the moringa plant in relation to nutritional benefits and have articulated that moringa is a super food (Koul & Chase 2015; Arshad & Takacsne, 2020). As a super food, the leaves also have high nutritional benefits similar to the seeds and pods. Previous studies by Moyo et al. (2011), Oduro et al. (2008), Abdulkadir, et al. (2016), Shih et al. (2011) and Arshad & Takacsne (2020) highlighted the proximate composition of *Moringa oleifera* leaves. However, these investigations did not specify the dimensions as well as the developmental stages at which the leaves were harvested, nor indicated whether the leaves were amassed as a composite sample rather than each specific stage of development as determined and deduced in this investigation. In this experiment, both L2 and L3 moringa leaves had a fat content similar to that reported by Oduro et al. (2008). While Bamishaiye et al. (2011) reported on the fat content of moringa leaves at early, mid and late stages of maturity it was noted that these leaf stages were not linked to specific dimensions as reported in this investigation and shown in Table 1.

Previous studies by Bamishaiye et al. (2011), indicated that crude fiber content of moringa leaves at different stages of maturity were consistently higher compared to the data for crude fiber recorded in Table 1. These differences could be related to variations in genetic lines and cultural practices as well as the time period in which these three stages were harvested. However, both investigations underlined the significance of maturity of plant tissues and their relationship with nutrient accumulation. Crude fiber levels derived from mature pods, green seeds and dried seeds were several folds higher than that obtained for leaves and flowers (Table 1). Apart from leaves and flowers, crude fiber levels were highest for dried seeds (314.5g/kg) followed by green seeds (293.8g/kg) and mature pods (222.8g/kg). Dried seeds accounted for 21.3g/kg and 86.5g/k more crude fiber than green seeds and mature pods (Table 1), thereby emphasizing that drying was more effective in preserving and enhancing nutritional characteristics as reported by Aremu & Akintola (2016).

Table 1. Proximate composition of the moringa plant at different stages of growth and development

Moringa plant parts[z]										
Proximate Composition	L1	L2	L 3	F 1	F2	F3	MP	GS	DS	LSD (0.05)
Fat g/kg	26.4^{e}	19.6^{d}	16.6^{c}	15.8^{c}	11.7^{b}	10.6^{a}	8.0^{a}	114.3^{f}	200.3^{g}	2.7
Crude Fiber g/kg	70.0^{c}	57.0^{a}	60.7^{b}	79.2^{d}	87.0^{e}	94.5^{f}	222.8^{g}	293.2^{h}	314.5^{i}	2.9
Crude Protein g/kg	251.6^{cd}	252.4^{cd}	287.1^{e}	254.5^{cd}	210.0^{b}	204.2^{b}	129.2^{a}	296.0^{e}	256.3^{d}	12.6
Ash g/kg	111.0^{a}	1749.5^{b}	179.4^{a}	1375.0^{b}	72.4^{a}	1193.6^{b}	98.7^{a}	45.5^{a}	1414.7^{b}	619.3
Dry Matter g/kg	965.0^{g}	926.1^{c}	938.1^{ed}	931.1^{d}	915.0^{b}	903.2^{a}	895.1^{h}	933.9^{de}	949.5^{f}	4.9
Moisture Content g/kg	350.0^{a}	739.0^{d}	619.0^{c}	689.0^{cd}	850.0^{e}	968.0^{f}	1049.0^{g}	661.0^{cd}	505.0^{b}	78.5

[z]Leaves stage 1 (L1), leaves stage 2 (L2), leaves stage 3 (L3), flowers stage 1 (F1), flowers stage 2 (F2), flowers stage 3 (F3), matured pods (MP), green seeds (GS) and dried seeds (DS).

Measurements undertaken for crude protein content (Table 1) were similar to levels reported by Bamishaiye et al. (2011). Such high levels of crude protein as shown in Table 1 were also reported by Oduro et al. (2008) and Abdulkadir (2016). This level of crude protein content is of particular nutritional significance as it may meet protein and energy requirements and boost the immune system against diseases with potential for inclusion as a dietary supplement.

The variability of ash content shown in Table 1 was due to the stage of maturity of the leaves and the other plant parts and therefore the differences obtained on studies reported by Moyo et al. (2011) and Abdulkadir et al. (2016) to specify whether analyses were undertaken on different plant parts or as composite sampling uptake by combined parts need to be clarified.

Previous studies on moisture content of moringa leaves were reported by Oduro et al. (2008), and Shih et al. (2011) but were inconsistent with the data presented in Table 1. Such differences would be attributed to several factors such as age of the tree, maturity and location and even impact of genetic lines (Bridgemohan et al., 2020).

Experiment 3

Screening different parts of *Moringa oleifera* showed the presence of different bioactive mineral derived from the leaves, flowers and seeds (Radovich, 2009), thereby confirming the highly nutritious nature of the plant and its potential use in human diets and formulation of dietary supplements and animal feed. Furthermore, it emphasized the significance in boosting food security, combating malnutrition and fostering rural development, although none of these studies actually focused on any particular stage of maturity as discussed above in experiment 2.

Mineral composition hereby reported in Table 2 is different to that articulated by Manju et al. (2018) as they focused on the selection of seeds that were harvested at a green stage then dried afterwards for analysis. However, in this study, the seeds used for analysis were harvested from tree-dried moringa pods which were extrapolated from the timelines indicated from the growth curve in Figure 1 and designated as the third stage of maturity (M3). This investigation therefore confirmed the importance of nutrient variability according to initial seed maturity consistent with recent reports by Bridgemohan et al. (2020).

Table 2. Mineral composition of moringa leaves and flowers at three stages of maturity, matured pods, green and dried seeds

	Moringa plant parts[z]									
Minerals (ppm)	L1	L2	L3	F1	F2	F3	MP	GS	DS	LSD (0.05)
Magnesium (Mg)	4209.0^{f}	3894.4^{ef}	4255.6^{f}	2137.7^{cd}	975.4^{a}	1595.0^{b}	1437.6^{a}	3609.2^{e}	2396.8^{d}	490.3
Sodium (Na)	2389.7^{f}	2547.9^{f}	1514.7^{e}	719.0^{bc}	742.6^{c}	968.2^{d}	200.3^{a}	546.0^{b}	224.8^{a}	189.8
Iron (Fe)	147.0^{g}	136.5^{f}	126.8^{e}	28.8^{b}	28.2^{b}	30.0^{b}	15.2^{a}	58.3^{d}	44.0^{c}	9.4
Potassium (K)	30210.7^{e}	23315.7^{d}	11411.9^{b}	15911.3^{c}	15882.6^{c}	16775.1^{c}	23723.1^{d}	12694.3^{b}	6555.3^{a}	1378.5
Boron (B)	16.6^{c}	23.1^{d}	20.7^{d}	14.4^{bc}	11.5^{ab}	14.0^{bc}	16.1^{c}	14.9^{c}	10.2^{a}	3.1
Calcium (Ca)	25667.6^{d}	29374.8^{e}	32404.2^{f}	4706.6^{c}	3553.5^{bc}	2639.9^{b}	892.1^{a}	1783.2^{a}	1343.1^{a}	1465.5

[z]Leaves stage 1 (L1), leaves stage 2 (L2), leaves stage 3 (L3), flowers stage 1 (F1), flowers stage 2 (F2), flowers stage 3 (F3), matured pods (MP), green seeds (GS) and dried seeds (DS).

Magnesium concentration ranged from 175.4ppm to 4255ppm (Table 2). Magnesium levels of moringa leaves were generally higher that flowers, mature pods, green seeds and dried seeds. However, magnesium contents were not significantly different according to the stage of maturity of harvested leaves. On the other hand, flowers at F1 accounted for the highest content of magnesium compared to F2 which was the lowest. Magnesium levels were notably higher for green seeds compared to dried seeds and matured pods (Table 2). Moreover, magnesium is a microelement that works with the macro element calcium to help to transmit nerve impulses in the brain. Magnesium is required in the plasma and extracellular fluid, wherein helping in maintaining osmotic equilibrium. Magnesium has a calming effect and works on the nervous system of those peoples, suffering from depression (Gupta et al., 2014) in support of Screeja et al. (2021) review which focussed on the nutraceutical and medicinal benefits of this plant.

Major differences in sodium levels among the various parts of the moringa plant were recorded and while L1 (2389.7 ppm) and L2 (2547.9 ppm) showed no significant differences between each other, sodium levels were significantly lower than L3 (4255.6 ppm) (Table 2). Likewise, F1 (719.0 ppm) and F2 (742.6 ppm) showed no differences in sodium content but had significantly higher sodium in flowers stage 3 (968.2 ppm). Matured pods (200.3 ppm) had the lowest sodium content while green seeds (546.0 ppm) and dried seeds (224.8 ppm) showed significantly lower sodium levels than leaves at all stages as well as flowers analysed at stages F1 and F2. Leaves showed the highest sodium levels and had significant differences to all moringa plant parts and stages. Sodium content of F3 was significantly lower than leaves, matured pods and seeds (Table 2). Despite these variations in sodium levels perhaps attributable to differences in Na uptake of by the plant material across agro-ecological regions, it must also be noted that this macro element is a critical source of electrolytes (Mulyaningsih & Yusuf, 2017).

Interestingly, Fe, which is commonly deficient in many plant-based diets, was unevenly distributed among the various parts of the moringa plant (Table 2). Accordingly, L1 (147.0 ppm), L2 (136.5 ppm) and L3 (126.8 ppm) highlighted significant differences in iron levels (Table 2). Matured pods (15.2 ppm), GS (58.3 ppm) and DS (44.0 ppm) showed no similarities in iron content with any other plant part. Iron levels in leaves were significantly different to flowers, matured pods, green and dried seeds. Flowers were significantly lower in iron content than seeds and leaves. Mature pods had the lowest iron level among all parts of the moringa plant (Table 2). The therapeutic manifestation of this essential trace element is extensively documented as a necessary component of haemoglobin and myoglobin for oxygen transport and cellular processes of growth and division (Kozat, 2008). Iron is also for normal functioning of the central nervous system and in the oxidation of carbohydrates, proteins and fats (Umar et al., 2007). Iron a has a role in energy metabolism as it facilitates transfer of electrons in the electron transport chain for the formation of ATP (Kozat, 2008). Iron regulation can also be targeted to metabolically manipulate immune cell function under pathophysiological conditions, and therefore the iron content in moringa plant parts could provide new therapeutic opportunities for future autoimmunity and cancer investigations (Cronin et al., 2019).

Moringa has potassium that is necessary to increase iron utilization and beneficial to people taking diuretics to control hypertension (Sodamade et al., 2013). The recommended daily allowance of potassium is 2000mg for adults (NRC, 1989) and *Moringa oleifera* can contribute 1.16% of the recommended daily allowance. In this study, among the leaf stages, potassium levels were (30210.7 ppm) for L1, (23315.7 ppm) for L2 and (11411.9 ppm) for L3 respectively and were significantly different to other plant parts (Table 2). F1 (15911.3 ppm),

F2 (15882.6 ppm), F3 (16775.1 ppm) were significantly lower than L1 and L2 but higher than L3. Matured pods (23723.1 ppm) had higher potassium levels than flowers, leaves at L2 and L3 while dried seeds (6555.3 ppm) had the least potassium. Matured pods had higher potassium levels than all other plant parts except L1. Green seeds were significantly lower than L1, L2, flowers at all stages, matured pods but had higher potassium levels than dried seeds. Dried seeds had the lowest potassium content compared to all other moringa plant parts and stages of maturity (Table 2).

Boron contents in moringa leaves were (16.6 ppm) for L1, (23.1 ppm) for L2 and L3 (20.7 ppm) (Table 2). L1 was significantly lower than L2, L3 but higher than F2 (11.5 ppm) and dried seeds (10.2 ppm). F2 displayed lower boron content compared to the other parts of the moringa plant except dried seeds. Matured pods were significantly higher than F2 and DS but significantly lower than L2 and L3 (Table 2). Boron is a trace element that is naturally present in many foods and available as a dietary supplement. It is a structural component of plant cell walls and is required for plant growth, pollination, and seed formation. Although research has not yet identified a clear biological function for boron as an essential nutrient for humans, the need to explore the implications of the nutritional and nutraceutical effects of boron levels in moringa plants and development of value-added products is required (Nielsen & Eckhert, 2019).

The concentration of calcium (Ca) in the *Moringa oleifera* varied according to plant part and stage of maturity of the specific part as shown in Table 2. Calcium content in moringa leaves showed that L1 (25667.6 ppm) and L2 (29374.8 ppm) and L3 (32404.2 ppm) were significantly different from each other as well as F1 (4706.6 ppm), F2 (3553.5 ppm), F3 (2639.9 ppm), matured pods (892.1 ppm), green seeds (1783.2 ppm) and dried seeds (1343.1 ppm) (Table 2). Flowers had significantly lower levels of calcium compared to leaves analysed at each stage of maturity (Table 2). Calcium is essential for a wide variety of functions in the body. It is present in the bones and teeth, and a small percentage is found in the blood and soft tissues, e.g. in the heart and kidneys, where it is responsible for nerve impulses and muscle contractions (Mulyansih & Yusuf, 2018). The relatively high levels of calcium in moringa leaves should be researched to determine the potential use as a postharvest dip or upon vacuum infiltrated in fruits to enhance membrane integrity and maintain firmness.

Moringa mineral composition highlighted a significant role in nutritional, medicinal and therapeutic properties. Due to its protection, *Moringa oleifera* can be viewed as a nutraceutical product or food, which will promote the exploration of its ability to cause autophagy in the future for the prevention and treatment of chronic diseases (Sreeja et al., 2021). The nutritional variations observed among the studies could be attributed to the genetic background of the plant, in terms of ecotype and cultivar, environmental factors that include the soil and climate as well as the cultivation method and the frequency of harvesting and age of the plant (Bridgemohan et al., 2020).

CONCLUSION

Moringa oleifera showed a single sigmoid shape curve and attained different stages of maturation after 25, 32 and 52 days for M1, M2 and M3 respectively. Proximate and mineral compositions which varied according to plant part at specific stages of maturity confirmed that the phytonutrients in this plant could find applications as food ingredients, infant formula and dietary supplements.

Conflict of interest

The authors declared no conflict of interest.

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