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Impact of Telfairia Mosaic virus on Medicinal and Economic Potentials of *Amaranthus viridis* L

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Authors' contributions

This work was carried out in collaboration among all authors. Author AAJM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript, Author EEE managed the literature searches, Author EOI managed the analyses of the study and Author ATO edited the manuscript. All authors read and approved the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To study the impact of Telfairia mosaic virus on the Medicinal and Economic Potentials of *Amaranthus viridis*.
Study Design: The research was carried out in a randomized block design.
Place and Duration of Study: Department of Botany, University of Calabar, Calabar, Nigeria between March and June, 2017.
Methodology: Seeds of *A. viridis* obtained were raised in a nursery, on germination inoculated with TeMV and impact on medicinal and economic values investigated.
Results: Results showed negative impact of TeMV with reductions in medicinal components in plant parts of *A. viridis* studied. The virus caused severe reduction in medicinal pigments of 61.4% for

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(chlorophyll *a*), 42.0% (chlorophyll *b*), 35.2% (ratio of chlorophyll *a*/*b*) and 56.6% (carotenoids). Phytochemicals of *A. viridis;* alkaloids, glycosides, saponins, tannins, flavonoids and polyphenols were significantly (*P=0.05*) decreased by TeMV. Decrease in leaf flavonoids was (60.0%), stem (51.3%) and root (34.8%). The virus engendered reduction in ash, fibre, carbohydrate and moisture with increase in protein. Effect on lipid was not significant. Leaf carbohydrate content had percentage reduction of (58.9%), stem (54.7%) and root (39.0%). Protein was positively impacted on by TeMV with increase of -18.4% (leaf), -10.5% (stem) and 10.4% (root).

Conclusion: The presence of medicinal nutrients in plant parts of *A. viridis* affirmed its whole plant usage in traditional medical practice. Telfairia mosaic virus decreased the medicinal (photosynthetic pigments, phytochemicals and proximate) nutrients of *A. viridis* affecting its therapeutic efficiency.

Keywords: Amaranthus viridis; pigments; medicinal nutrients; telfairia mosaic virus.

1. INTRODUCTION

Amaranthus viridis L. (Amaranthaceae) is an annual herbaceous plant with an erect stem. It is eaten traditionally as a vegetable in Nigeria, and other parts of Africa [1]. In Nigeria, leafy vegetables are traditionally cooked and eaten as relish with starchy staple food. *Amaranthus viridis* contain large amount of phytochemicals, protein, ash, fibre, fat, carbohydrate, amino acids, minerals, vitamins and antinutrients with known health and industrial benefits [2]. Because of its rich phytochemicals and phytonutrients, *A. viridis* is used in India and Nepalese traditional medicine to reduce labor pains [3]. The Negritos of the Philippines apply the cruised leaves directly in the treatment of eczema, psoriasis and rashes [4]. Medically the vegetable is used as: antihyperlipidemic and anticholesterolemic [4], antimicrobial [5], anti-inflammatory [6], antinociceptive, antipyretic, antihelmintic, hepatoprotective [7], antifungal [8], antihyperglycemic, hypolipidemic and antidiabetic [9], antiviral [10], cardio protective [11]. In traditional medicine, the whole plant of *A. viridis* is useful in the treatment of pain and fever.

Plants react when subjected to virus infection by the production of several reactive oxygen species (ROS) which causes damaging effects on host plant cells. The host-virus interaction suggests a highly complex network of plant responses and the viral counter-responses which greatly impact the physiology of the plant [12]. *Amaranthus viridis* is a vegetable of high economic and medicinal values. [13] had focused on the effect of TeMV on enzymes activities of *A. viridis.* [14] reported the influenced of TeMV on growth, yield and phytonutrients of *A. viridis*. There is no report on the impact of TeMV on photosynthetic pigments, phytochemicals and proximate nutrients of *A. viridis*, which provides useful information on its therapeutic efficiency. This study was designed to investigate the danger posed by this virus on the medicinal and economic potentials of *A. viridis* with the view to advance research on TeMV control to maximize the worth of this important vegetable.

2. MATERIALS AND METHODS

2.1 Planting Materials

Seeds of *A. viridis* used in this study were purchased from a farmer at Akparabong, Ikom Local Government Area of Cross River State, Nigeria whose plants were monitored on the field for symptoms expression. The seeds were raised in nursery before transplanting into steam-sterilized soil in polyethylene bags. Investigations were carried out in the Department of Botany screenhouse, University of Calabar, Nigeria. The seeds spouted eight days after planting (DAP) and the seedlings inoculated at two-leaf stage

2.2 Inoculum Preparation and Plant Inoculation

The isolate of TeMV used was obtained from the Federal Biological Research Centre for Agriculture and Forestry Braunschweig, Germany. Telfairia mosaic virus infected leaf stored in liquid nitrogen was reactivated by homogenizing the leaf tissue in a sterile laboratory mortar and pestle in cold disodium phosphate buffer 0.03 M, pH 8.0. The inoculum obtained was applied mechanically by leaf-rub on *A. viridis* pre-dusted with carborundum (800-mesh). The inoculated leaves were rinsed with water and observed for symptom development under screenhouse condition at 25±3^{o}C. Before *A. viridis* plants were inoculated, those to be inoculated and those of the control were arranged in a randomized block design (RBD) containing a total of 60 plants. Thirty plants were inoculated with the virus and the other thirty inoculated with only the buffer to serve as the

control. Plants inoculated with TeMV were left for symptom development (8-10 days) such as mosaic, severe leaf malformation and distortion characteristics of TeMV infection.

2.3 Chlorophyll and Carotenoids Estimation

Photosynthetic pigments estimation was carried out using leaf samples collected from the control and virus inoculated plants of *A. viridis* from same position and age showing distinct symptoms to maintain sample uniformity. Leaf samples were collected at two weeks interval for a period of 12 weeks. Chlorophyll content was determined by extraction with 80% acetone [15] and absorbance readings taken using a spectrophotometer (Pye Unicam SP8-190, Spec. UK). Specific absorption coefficients were used for the calculation of chlorophyll *a*, chlorophyll *b* and carotenoids contents and expressed in mg per g tissue.

Chlorophyll *a* (mg g^{-1} fresh leaf) =12.7 (A_{663}) - 2.69 (A_{645})V/1000W
Chlorophyll *b* content (mg g^{-1} fresh leaf) = 22.9 (A_{645}) - 4.86(A_{663})V/1000W

Where A663 and A645 represent absorbance of at 663 and 645

V: volume of acetone-chlorophyll extract in ml
W: Fresh weight of leaf sample in gram

Absorption coefficients: 12.7, 2.69, 22.9 and 4.86.

Total chlorophyll = chlorophyll *a* + chlorophyll *b*

Carotenoids mg g^{-1} = 3.984(A_{451})V/100W

2.4 Sample Analysis

At 8 weeks after inoculation (WAI), leaf, stem and root parts of the vegetable were collected, dried, pulverized and used to analyse phytochemicals and phytonutrients in *A. viridis*. The amount of phytochemicals in plant parts of *A. viridis* were determined thus; alkaloids [16], tannins [17], saponins [18], flavonoids [19], phenols were determined by spectrophotometer method.

2.5 Statistical Analyses

The data obtained were analyzed using the independent t-Test to determine significant differences between means of inoculated and control plants. Results were also expressed as percentage difference and differences between mean values were determined at 5% probability.

3. RESULTS

3.1 Impact of Telfairia mosaic virus on photosynthetic pigments of *Amaranthus viridis*

Photosynthetic pigments of *A. viridis* were decreased by TeMV infection. Virus inoculated plants had lower pigments content compared to the control. The virus caused decrease in photosynthetic pigment levels at all periods of growth. Decrease in chlorophyll *a*, chlorophyll *b*, chlorophyll *a* + *b* and ratio of chl *a*/*b* levels due to TeMV infection at 12 weeks after inoculation (WAI) presented mean decrease of 24.35 ± 0.01, 15.02 ± 0.01, 39.37 ± 0.01 and 1.65 ± 2.72E-16 mg/g respectively compared to control plant values of 63.01 ± 0.01, 25.88 ± 0.01, 88.2 ± 0.02, 2.5 ± 0.01 mg/g respectively. The level of carotenoids in inoculated plant at 2 WAI presented decrease in 9.02 ± 0.01 mg/g as against 16.43 ± 0.01 mg/g. Corresponding decrease in values at 12 WAI of 10.31 ± 0.01 mg/g compared to control value of 21.49 ± 0.01 mg/g were also observed (Table 1).

3.2 Impact of Telfairia Mosaic Virus on Phytochemicals of *Amaranthus viridis*

Phytochemicals of *A. viridis* were severely impacted on by TeMV stress with significant (*P=0.05*) reductions in all plant parts (Table 2). The virus caused reduction in glycosides, polyphenols, saponins, alkaloids and tannins. Results revealed a general trend with the highest amount of phytochemicals observed in leaf and lowest in root samples. Tannins were not detected in root samples of *A. viridis*. Reduction in flavonoids and polyphenols in leaf, stem and root of inoculated plant samples were 8.00 ± 0.06, 7.99 ± 0.33, 7.99 ± 0.33 mg/100 g and 14.41 ± 0.1, 12.22 ± 0.3, 9.06 ± 0.1 mg/100 g respectively. Corresponding values for the control were 20.01 ± 0.56, 16.41 ± 0.02, 10.32 ± 0.02 mg/100 g and 30.71 ± 0.1, 25.01 ± 0.1, 29.22 ± 0.1 mg/100 g.

3.3 Impact of Telfairia Mosaic Virus on Proximate Composition of Amaranthus viridis

All proximate nutrients of A. viridis were negatively impacted on by TeMV with the exception of protein. Proximate nutrients of inoculated A. viridis plant parts were significantly

(P=0.05) lower in amount than their control counterparts (Table 3). The virus caused decrease in fibre, carbohydrate, moisture and ash. The amount of protein in TeMV inoculated plant parts was higher than in the control. Decrease in fat content of inoculated plants was insignificant in all plant parts. The root had lower decrease in all proximate nutrients when compared to the stem and leaf of both the control and inoculated plants. Reduction in fibre content of leaf, stem and root of TeMV inoculated A. viridis were 2.09 ± 0.03, 2.23 ± 0.06 and 2.19 ± 0.06 g/100 g respectively compared to control plant values of 5.08 ± 0.06, 4.92 ± 0.03 and 3.59 ± 0.06 g/100 g respectively. Decrease in carbohydrate and moisture in leaf samples of inoculated plants had values of 38.12 ± 0.26 and 38.12 ± 0.26 g/100 g as against values of 84.67 ± 0.33 and 81.86 ± 0.13g/100 g for control plants. Increase in protein due to TeMV-induced stress in leaf, stem and root samples were 5.98 ± 0.1, 5.47 ± 0.3 and 3.82 ± 0.1 g/100 g respectively. Corresponding mean values for control samples were 5.05 ± 0.1, 4.95 ± 0.26 and 3.46 ± 0.26 g/100 g.

4. DISCUSSION

Photosynthetic pigments, phytochemicals and proximate nutrients were used to investigate the impact of TeMV on the medicinal and economic potentials of *A. viridis*. Interaction of TeMV with *A. viridis* resulted in alterations in cellular constituents due to multiplication of TeMV particles in the infected plants. Telfairia mosaic virus infection altered biochemical compounds of *A. viridis* such as chlorophylls, carotenoids, phytochemicals and proximate nutrients depicted by severe reductions. Reduction in these health promoting and economically valuable nutrients is a cause for concern. Reduction in photosynthetic pigments occasioned by TeMV affects plant health and productivity, decreases the medicinal and economic potentials. Findings of this study are similar to report of photosynthetic pigments reduction in chilli plant by Cucumber mosaic virus [20], in *Telfairia occidentalis* infected with Telfairia mosaic virus [21]. Decrease in chlorophyll pigments by TeMV threatens its medicinal potentials which is of immense benefit to man. Medicinally, chlorophyll is a pigment that enhances the overall well-being of humans: it has potent anti-inflammatory properties and has been used against a host of anti-inflammatory conditions such as arthritis, sinusitis, pancreatitis and respiratory conditions. Chlorophyll is one of nature's most potent chelating agents that bind heavy metals in the body, helping to render them useless for elimination. Chlorophyll is an effective deodorizer to reduce bad breath, urine, fecal waste and body odor. It possesses some anti-atherogenic activity. It can be used to treat wound naturally, in surgical wound healing, in the prevention of infection, in the treatment of acne [22]. Chlorophyll *a* and *b* help in the treatment of constipation, halitosis, pelvic inflammatory diseases, aid tissue regeneration, promote production of erythrocytes [23,24]. The pigment stimulates anti-aging hormones, thus, helps the body to rejuvenate and build itself [25]. Chlorophyll is an antioxidant powerhouse that protects against free radical damage. It is a great source of vitamin A, C, E, K and minerals like magnesium, iron, Calcium and potassium. Vitamin K in chlorophyll stimulates adrenal system and helps in detoxification [26].

Naturally, chlorophyll produces oxygen, and increases oxygen flow throughout the body. When green vegetables are eaten, chlorophyll allows blood to transport oxygen to cells. It oxygenates the entire body-feeding the cells with hemoglobin and brings more oxygen into cells, while at the same time strengthening cell walls from oxidative damage. The greener the vegetable, the higher is it chlorophyll content and the greater its oxygen carrying ability. Low chlorophyll level orchestrated by TeMV may lower oxygen production and carrying ability of chlorophyll. Insufficient oxygen reduces energy production and a drop in metabolism. Increasing the intake of chlorophyll-rich foods increases the oxygen uptake by the cells of our bodies.

Severe mosaic symptoms caused by TeMV is the major cause of decrease in leaf chlorophyll concentration of *A. viridis* which implies decrease in its greenness and medicinal potentials. Chlorophyll is a blood builder used in the treatment of anemia in patients with hemoglobin deficiencies. It is a common practice for fresh leaves of the vegetable to be crushed in water and taken to build blood levels. That is why chlorophyll is described as ''the blood of plant'' and chlorophyll-rich foods have been linked with increasing hemoglobin content. It not only cleanses the blood of impurities, but also builds up the blood with important nutrients, promotes regularity, and inhibits cellular damage from radiation. Chlorophyll boost immune system. Reduction in chlorophyll is threatening because eating food rich in chlorophyll fortifies our bodies against health disorders. Eating green vegetable like non-infected *A. viridis* increases our

Table 1. Impact of Telfairia mosaic virus on photosynthetic pigments of *Amaranthus viridis* mg/g tissue

WAI	Chl *a*		Chl *b*		Chl *a*/*b*		Carotenoids	
	Control	Inoculated	Control	Inoculated	Control	Inoculated	Control	Inoculated
2	27.54±0.04	20.26±0.02*	14.6± 0.02	11.15± 0.01*	2.37±0.01	1.82± 0.02*	16.43±0.01	9.02± 0.01*
4	39.67±0.02	21.72±0.01*	18.55±1.137	13.3± 2.18E-15*	2.06±0.02	1.63 ± 0.01*	18.28±0.01	9.91± 0.00*
8	56.39±0.01	23.41±0.02*	22.18±0.01	14.17 ± 0.01*	2.54±0.01	1.65 ± 2.72E-16*	20.25±0.01	9.78± 0.01*
12	63.01±0.01	24.35±0.01*	25.88±0.01	15.02 ± 0.01*	2.5± 0.01	1.62 ± 0.01*	21.49±0.01	10.31±0.01*

*Means of three replicates ± SD, P=0.05, * = Statistically significant*

Table 2. Impact of Telfairia mosaic virus on phytochemicals of *Amaranthus viridis*

Phytochemicals*	Plant part	Control (mg/100 g)	Inoculated (mg/100 g)
Alkaloids	Leaf	2.80 ± 1.12	1.31± 0.33
	Stem	2.42 ± 0.06	1.29 ± 0.06
	Root	0.73 ± 0.53	0.54 ± 0.02
Glycosides	Leaf	2.57 ± 0.02	1.53 ± 0.029
	Stem	2.10 ± 0.02	1.45 ± 0.02
	Root	3.80 ± 0.1	1.38 ± 0.01
Saponins	Leaf	3.40 ± 0.03	1.05 ± 0.03
	Stem	3.51 ± 0.03	2.57 ± 0.03
	Root	2.63 ± 0.03	2.01 ± 0.03
Tannins	Leaf	0.20 ± 0.13	0.10 ± 0.13
	Stem	0.17 ± 0.12	0.09 ± 0.13
	Root	ND	ND
Flavonoids	Leaf	20.01 ± 0.56	8.00 ± 0.06
	Stem	16.41 ± 0.02	7.99 ± 0.33
	Root	10.32 ± 0.02	6.73 ± 0.33
Polyphenols	Leaf	30.71 ± 0.1	14.41 ± 0.1
	Stem	25.01 ± 0.1	12.22 ± 0.3
	Root	29.22 ± 0.1	9.06 ± 0.1

*Means of three replicates ± SD, P=0.05, * = Statistically significant, ND = Not detected*

Table 3. Impact of telfairia mosaic virus on proximate nutrients of *Amaranthus viridis*

Proximate nutrients	Plant part	Control	Inoculated (g/100 g)
Ash	Leaf	5.81 ± 0.2	3.56 ± 0.06*
	Stem	5.15 ± 0.06	3.79 ± 0.03*
	Root	3.99 ± 0.03	2.97 ± 0.03*
Protein	Leaf	5.05 ± 0.1	5.98 ± 0.1*
	Stem	4.95 ± 0.26	5.47 ± 0.3*
	Root	3.46 ± 0.26	3.82 ± 0.1*
Fat	Leaf	4.97 ± 0.03	4.85 ± 0.1
	Stem	5.03 ± 0.06	4.93 ± 0.1
	Root	4.76 ± 0.1	4.66 ± 0.2
Fibre	Leaf	5.08 ± 0.06	2.09 ± 0.03*
	Stem	4.92 ± 0.03	2.23 ± 0.06*
	Root	3.59 ± 0.06	2.19 ± 0.06*
Carbohydrate	Leaf	84.67 ± 0.33	38.12 ± 0.26*
	Stem	83.95 ± 0.1	70.75 ± 0.26*
	Root	50.24 ± 0,1	45.80 ± 0.3*
Moisture	Leaf	81.86 ± 0.13	48.14 ± 0.3*
	Stem	81.52 ± 0.13	69.71 ± 0.3*
	Root	89.78 ± 0.1	75.16 ± 0.1*

*Means of three replicates ± SD, P=0.05, * = Statistically significant*

protection from free radicals, not only by delivering new antioxidants to the body, but by rejuvenating already existing ones. Consuming chlorophyll helps to reduce total and low density lipoproteins (bad) cholesterol, as well as sweet and healthy food cravings and overall caloric intake. The pigment helps boost energy levels. Chlorophyll is the latest superfood ingredient added to energizing beverages. It not only accelerates ATP production in plants, it benefits human energy production as well [22] necessitating the control of TeMV on *A. viridis* to maximize chlorophyll levels.

Impact of TeMV on host cellular led to decrease in carotenoids. Plant carotenoids play beneficial roles in the health of humans. Carotenoids in mammals function as vitamin A precursor, stimulating immune system and antioxidant activity [27]. Humans who consume TeMV infected *A. viridis* may have low levels of vitamin A which may lead to night blindness (see poorly in dim light). High carotenoids diets helped reduce symptoms of eyestrain (dry eyes, headaches, and blurred vision) and improve night vision [28]. Carotenoids have diverse bioactive and chemical properties and can be used as visible indicators of health. Foods high in carotenoids appeared to be protective against head and neck cancer [29], breast, cervical, ovarian and colorectal cancer, type 2 diabetes, obesity, cardiovascular diseases and others [30,31]. The health-related benefits linked with high carotenoids intake are enhanced immune system functions and reduced risk of developing degenerative chronic diseases, such as aged-related macular degeneration [32]. Carotenoids possess antioxidant activity [33]. They are important components of the dark brown pigment melanin, found in hair, skin, and eyes which absorbs high-energy light and protects these organs from intercellular damage. The positive effects of high-carotenoids diets on the texture, clarity, color, strength, and elasticity of skin have been studied [34]. Economically, degradation products of carotenoids; damascones and damascenones are used as fragrances in perfumes industry [35]. Carotenoids are used in cosmetics industry and in the foods, feeds, additives, pharmaceuticals, nutraceuticals, and fine chemicals sectors. Therefore, care must be taken to protect this vegetable from TeMV infection in order to maintain normal levels of these useful plant pigments. There is a huge market for carotenoids in the industrialized world, where the pigments are produced both as commodities and luxury goods. Carotenoids reduction by TeMV in this study implies reduced medicinal efficiency and economic value of *A. viridis.* Reduction in carotenoids pigments by TeMV infection in this study may be attributed to alteration in host cells mechanisms. Their reduction implicates TeMV as an inhibitor of carotenoid biosynthesis as the virus block phytoene desaturase (PDS), an enzyme that catalyze the conversion of phytoene to carotene during infection. This finding is in consonance with precious report of Cucumber mosaic virus as a carotenoid inhibitor [36].

Biochemical changes in infected *A. viridis* resulted in decreased quantity of phytochemicals. Plants are the source of food and medicine to man. Various parts of the plant have been used to demonstrate the therapeutic properties of plants. The leaf, stem and root parts of *A. viridis* contain important phytochemicals that have health-protecting qualities thus used for the treatment of a wide range of diseases. Phytochemicals were negatively impacted on by TeMV infection with severe reductions. This report is in agreement with previous results of reduction in alkaloids and flavonoids of *Telfairia occidentalis* by TeMV [37], alkaloids and saponins of *Cucurbita moschata* by a Nigerian strain of Morocccan watermelon mosaic virus [38] Alkaloids present in leaf, stem and root of *A. viridis* are used as emetic, anti-cholinergic, antitumor, diuretic, sympathomimetic, antimicrobial (antiviral, antibacterial), antidepressant, antitussigen, antihypertensive, anti-inflammatory, hypoanalgesic and miorelaxant [39]. Alkaloids strengthen the blood capillaries and prevent the small cutaneous haemorrhages in the aged. Some flavonoids relieve cramps of the smooth coronary arteries. They also possess antiallergic effects, for its antithrombotic promotion and as a protection for gastric mucosa. Alkaloids are haemolytically active and widely used as therapeutic agents in cancer management [40]. They increase the secretion of digestive juices and appetite in patients. These phytochemicals account for the use of *A. viridis* in traditional medical practices. Glycosides function as purgative, and for the treatment of skin and heart diseases, anticancer. Glycosides inhibit turmour growth and protect against gastrointestinal infections [41]. Many plants store medically important chemicals in the form of inactive glycosides. Saponins possess pharmacological and medicinal properties; haemolytic and antimicrobial [42]. Food rich in saponins are significant in human nutrition in controlling plasma cholesterol level, preventing peptic ulcer, osteoporosis and in reducing the risk of heart disease [43], saponins can also be used to restrain dental caries and platelet aggregation, in the treatment of hypercalciuria in humans, and as an antidote against acute lead poisoning [44]. Tannin-rich plants are used in Ayurvedic medicine for the treatment of leucorrhoea, rhinorrhoea and diarrhea as well as astringent [45], diarrhea and dysentery [46]. Antihelmintic effects of tannins, it's potential for anticancer prevention [47]. Flavonoids exhibit low toxicity and show several biological effects such as anti-inflammatory, antiulcer and antihepatotoxic actions. Most flavonoids containing plants are diuretic or antispasmodic agent. Others have antibacterial and antifungal properties [48]. Flavonoids contribute to low mortality rates in people consuming high amount of plant-based foods. Polyphenols are natural antioxidant used as nutraceuticals. They prevent blood clotting, anticancer, anti-inflammatory agent and function in the prevention of heart ailment. Polyphenols possess antibacterial, anti-inflammatory, antiallergic, antiviral and antineoplastic activity [49].

Fortunately, these natural chemical nutrients are widely distributed in *A. viridis* and they play important roles in the human body when eaten in adequate amounts. Natural food products are increasing in demand. Consumer's preference for food products without any artificial ingredients and preservatives is also increasing, creating demand for clean label products. Consumers are seeking for food products with nutritional and health benefits, therefore, manufacturers are focusing on using natural ingredients in food and beverages to meet the consumer's demands. Currently the food industry uses artificial flavours and synthetic colours to produce food products which are harmful to health due to the presence of chemical additives and preservatives. Phytochemicals are natural ingredients sourced from plants that can be the perfect alternatives for chemical additives and preservatives. Phytochemicals are use in different food products (bakery, dairy, beverages and others) to meet the growing consumer demand. In addition to providing flavours and colours, various phytochemicals provide multiple benefits to finished products. Natural ingredients are also in high demand in nutraceuticals, pharmaceuticals, cosmetics and animal feed, which offer additional benefits to phytochemicals market forcasted to reach US$ 9.0 billion by the end of 2029 [50]. Economically, reduction in phytochemicals caused by TeMV is worrisome demanding urgent attention directed towards its control.

Impact on *A. viridis* by TeMV led to reduction in proximate nutrients. Findings of the present study coincide with report of reduction in fibre and ash of *A. hybridus* due to TeMV infection [51], fibre, carbohydrate [52]. Adequate nutrition in human plays a critical role in building a strong immune system capable of protecting the body against infection. Poor nutrition emanating from food consumption with low nutrient levels exposes humans to various diseases. People who consumed TeMV infected *A. viridis* obtain

low nutrients levels occasioned by their depletion. Decrease in these nutrients weakened human immune-defense and resistance to diseases. However, TeMV had a positive impact on protein as revealed by increase in content. Increase in protein found in inoculated plants in this study is in line with report of increase in protein in *Passiflora edulis* infected with Telosma mosaic virus [53]. Increase in protein observed in inoculated samples of *A. viridis* could be due to virus multiplication which entails the synthesis of virus specific abnormal protein that accumulates and ultimately raises the amount over the control. Reduction in fibre content by TeMV infection is a cause of concern because high fibre diet is linked to reduced risk of heart disease, certain forms of cancer, diabetes, diverticulitis, gastrointestinal disorders and obesity hence, the need for TeMV control.

5. CONCLUSION

Medicinal and economic potentials of *A. viridis* L. investigated were severely impacted by TeMV with associated reductions in content. The virus engendered reduction in chlorophyll *a*, chlorophyll *b*, ratio of chlorophyll *a*/*b* and carotenoids at different stages of growth. Results revealed decreased amount of alkaloids, glycosides, flavonoids, tannins, saponins and polyphenols in leaf, stem and root of *A. viridis* due to TeMV infection. Ash, fibre, carbohydrate and moisture content were significantly reduced by the virus. The virus however, caused increase in protein. Impact of the virus on fat was not significant. Decrease in levels of these medicinal nutrients decreased *A. viridis* therapeutic efficiency as well as its market value.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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