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Abstract

Impact of Foliar-applied Plant Extracts on Growth, Physiological and Yield Attributes of Potato (*Solanum tuberosum* L.)

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Abstract: The current reliance on pesticides and synthetic fertilizers has been vital to sustain and even increase agricultural production. The continuous, excessive use of these traditional practices has negatively affected consumers' health and burdened the ecosystem. The use of plant extracts has the ability to improve plant growth and agricultural productivity. This study was, therefore, conducted to determine the effect of foliar plant extract application on potato growth, as well as on certain physiological and yield attributes. Treatments included extracts of the seaweed *Ascophyllum nodosum*, aloe vera leaves, garlic bulbs and moringa leaves. From four weeks after planting onwards, five healthy, equal-sized potato plants received 50 mL of the above-mentioned plant extracts as foliar application. These treatments were repeated weekly until harvesting. Data on growth and physiological parameters were collected weekly. Pre-harvest foliar application of various plant extracts significantly enhanced ($p \leq 0.05$) plant growth and yield attributes of potatoes. Best growth and yield responses were observed following ANE and MLE application. A positive influence of various foliar plant extract applications on growth and yield of potatoes was demonstrated. Further validation of the response of other crops is still necessary to promote the adoption of this approach.

Keywords: biostimulants; food security; plant extracts; potato; sustainable agriculture

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1. Introduction

Potato (*Solanum tuberosum* L.) is a member of the Solanaceae family, native to South America, but is now grown in most parts of the world [1]. Amongst the cash crops, potato is one of the world's most important non-grain food crops with a global production of about 376 million tonnes, with China as the largest producer contributing approximately 94 million tonnes annually [2]. Potato is also recognized as a staple food, being the third most-consumed food crop worldwide, following rice and wheat [1]. The worldwide *per capita* potato consumption reached 33.1 kg in 2020, this is possibly due to the health and nutritional benefits potato offers [2]. According to Zaheer et al.[3] potato is an excellent source of dietary fibre, carbohydrates, high-quality protein, vitamins, minerals and other metabolites. Being rich in health-promoting metabolites, potato possesses high antioxidant activity, which helps to reduce the risk of chronic diseases, including heart disease, diabetes and cancer [4].

In the last couple of decades, there has been a rapid increase in potato demand. For all potato growers, it has, therefore, become of immense importance to produce this crop profitably, at a minimum input cost. Additionally, modern agriculture demands sustainable crop production, searching for alternative methods to sustain plant development with little or no compromise to yield. Potato farmers are facing a major challenge of biotic and abiotic factors aligned with climate change. These include drought, salinity, weed infestation, pests and diseases, which can all devastatingly affect growth and yield of potato [5]. Given these challenges, synthetic pesticides and inorganic fertilizers have become vital for the production of crops and their protection against biotic and abiotic constraints [6]. The current reliance on industrially-based inputs may, however, pose multiple threats to human health and impart harmful effects on the ecosystem [7]. In addition, Lucas *et al*. [8] revealed that the continuous, excessive usage of such chemicals might result in the development of new pathogen strains that could become difficult to control, despite the efficacy of the chemical. The aim of modern plant agriculture is, therefore, to reduce the utilization of these chemicals to a minimum; thus, making crop farming simpler and offering healthier, safer and sustainably produced goods.

Farmers are, therefore, continuously exploring and developing alternative approaches to crop farming, trying to overcome challenges of long-term production viability [7]. Among several proposed strategies, the use of plant extracts has been identified as a promising, innovative, eco-friendly and sustainable approach that could improve crop production and crop protection. Recent studies have tested this method on a broad spectrum of solanaceous crops, such as potato [9], sweet pepper (*Capsicum annuum* L.) [10] and tomato (*Solanum lycopersicum* L.) [11,12]. The present study, therefore, aims to evaluate the influence of foliar application of plant extracts on growth, certain physiological and yield attributes of potato.

2. Material and Methods

Plant material and growing conditions

A pot experiment was performed in a glasshouse at the Controlled Environment Facility (CEF) of the University of KwaZulu-Natal, Pietermaritzburg, South Africa (29°37'32.9"S 30°24'18.8" E). The environmental conditions inside the glasshouse were maintained at 25 ± 2 °C and 65 % relative humidity (RH) during the day, while temperature and RH were kept constant at 13 ± 2 °C and 72 % at night, respectively. Locally purchased baby potatoes, cv. 'Sifra', were planted as seed tubers at a depth of 10 cm into 10 L plastic pots filled with a mixture of sandy soil and Gromor® (Gromor, Cato Ridge, South Africa) potting mix. Plants were irrigated using automated drip irrigation system, dispensing approximately 50 mL per 10 L pot daily.

Experimental design

The study was laid out following a completely randomized design (CRD) with five replications. Five healthy, similar-sized 'Sifra' sprouted baby potatoes, randomly selected, were used per treatment, with five seed tubers per replicate, giving 25 experimental units (10 L pots). The experiment consisted of four treatments, namely ANE (brown algae *Ascophyllum nodosum* extract), MLE (moringa leaf extract), GBE (garlic bulb extract) and AVE (aloe vera leaf extracts), plus the control (no extract application). The above-mentioned treatments were directly applied to potato leaves using a hand-held pressure sprayer, each plant received 50 mL. The first foliar application of treatments was performed four weeks after planting (vegetative stage), and treatment applications were repeated weekly until harvest.

Extracts preparation

Plant materials used for extracts preparation were obtained from various suppliers. Brown algae (*Ascophyllum nodosum)* powder (Nature's Choice) was bought locally (Dis-Chem, Woodburn Mall, Pietermaritzburg, South Africa), whereas healthy aloe vera plants were bought locally from Woodland nursery, (Pietermaritzburg, South Africa). Fresh moringa (*Moringa oleifera*) leaf powder (MLP) was supplied by a commercial supplier (runKZN, Pietermaritzburg, South Africa), while fresh Egyptian white garlic was bought from a local supermarket. The extracts used, ANE, AVE, MLE and GBE were prepared following the procedure described by [12], with slight modifications.

Determination of vegetative growth and certain physiological and yield parameters

- Plant height, number of leaflets and number of leaves

Plant growth parameters, including plant height, number of fully expanded leaves and leaflets, were recorded from the first treatment application until tuber bulking stage of potato growth and development, at 7-day intervals. Plant height (cm) was measured from the base of the stem to the tip of the terminal bud using a tape measure. The number of leaves and leaflets were counted manually.

- Leaf area

From the first treatment application until the tuber bulking stage, leaf area of the entire potato plant was estimated directly from leaf length and width measurements. Leaf area was then calculated using the formula described by [13].

$$LA = 11.98 + 0.06\ L \times W, \quad (1)$$

where LA = Leaf area (cm^2), L = leaf length (cm) and W = leaf width (cm).

- Leaf chlorophyll content index

Leaf chlorophyll content index was determined using a portable, non-destructive and lightweight instrument (CCM-200plus - Opti-Sciences Inc., Hudson, NH, USA). At tuber bulking stage, a total of four plants, randomly selected from each treatment, were measured.

- Yield and fresh tuber mass

At the mature tuber stage, all tubers were harvested from all replicates. Total tuber yield (tuber number/plant) and tuber mass (g) were recorded immediately after harvesting.

- Statistical analysis

Results obtained were subjected to one-way analysis of variance (ANOVA) using GenStat statistical software (GenStat®, 18th edition, VSN International, UK). Means separation were performed using Duncan's multiple range test with at a 5 % ($p \leq 0.05$) significance level.

3. Results

Plant extracts were able to improve growth, certain physiological and yield attributes of potatoes (Table 1). Growth parameters, such as plant height, number of leaves and leaflets, as well as leaf area, were significantly increased ($p \leq 0.05$) by plant extract foliar application, with ANE and MLE showing an outstanding and significant performance (Table 1). Consequently, these two treatments yielded tallest plants (28.56 and 27.60 cm, respectively), higher number of leaflets (51.6 and 55, respectively), number of leaves (15.13 and 15.87, respectively) and larger leaf area (89.89 and 84.01 cm^2/cm^2, respectively) compared to AVE, GBE and the control (Table 1). The physiological response of potato plants was positively influenced by foliar application of plant extracts, especially ANE, AVE and MLE; hence, recorded higher leaf chlorophyll content index (34.45, 34.89 and 33.88, respectively) than GBE and the control(Table 1). Foliar application of plant extract also had a considerable effect on potato yield parameters, particularly total tuber yield and fresh tuber mass. ANE notably had a pronounced effect on yield attributes, thus, produced more yield (10.00) with heavier fresh mass (177.90 g) than other treatments AVE, GBE, plus the control (Table 1).

Table 1. Growth, physiological and yield response of potatoes following plant extract applications.

Treatments	Plant height (cm)	No. of leaflets	No. of leaves	Leaf area (cm^2/cm^2)	Leaf chlorophyll index (CCI)	Total yield (tubers/plant)	Fresh tuber mass (g)
Control	24.26c	42.67d	12.73c	64.91e	28.78b	6.33b	130.5d
ANE	28.56a	51.6b	15.13a	89.89a	34.45a	10.00a	177.90a
AVE	24.37c	47.53c	13.87b	70.54d	33.88a	7.33b	144.6cd
GBE	26.43b	48.87bc	14.20b	76.60c	30.3b	6.33b	155.4bc
MLE	27.60a	55.00a	15.87a	84.01b	34.89a	8.00b	164.1ab
LSD	**2.20**	**2.88**	**0.85**	**3.52**	**2.898**	**1.82**	**17.04**
F pr.	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**0.006**	**0.001**

NB: Values followed by different lower-case letters in each column are statistically different according to Duncan's multiple range test ($p \leq 0.05$). **Control** (no application), **ANE** (*Ascophyllum nodosum* extract), **MLE** (moringa leaf extract), **GBE** (garlic bulb extract) and **AVE** (aloe vera leaf extract). Values are means (n = 5).

4. Discussion

Enhanced vegetative growth, physiological and yield attributes could be due to the biofertilization and biostimulatory effect of plant extracts [10]. ANE and MLE biofertilization and biostimulatory effect has been previously reported on potatoes [9], sweet pepper (*Capsicum annuum* L.) [10] and tomato (*Solanum lycopersicum L.*) [12]. Both, ANE and MLE, are excellent sources of minerals, including the macro- as well as micro-nutrients N, P, K, Ca, Mg, Zn and Na [14]. The presence of such minerals in the extracts increases nutrient availability, especially N, P, K, Mg and Zn, to the plant, boosting vegetative growth, physiological and yield attributes [15]. In addition to minerals, growth, physiological and yield promotion by ANE and MLE could also be ascribed to their bio-stimulatory effect, due to the presence of phytohormones, such as auxins [indole-3-acetic acid (IAA)], gibberellins (GAs) and cytokinins (zeatin)[15,16]. The presence of such growth-promoting plant hormones in ANE and MLE could possibly induce the biosynthesis of endogenous plant hormones. Application of ANE and MLE, therefore, can modulate physiological processes, including cell expansion through cell division and cell elongation, resulting in vegetative growth and yield promotion (Table 1) as observed by Rayorath et al. [15] in *Arabidopsis thaliana* (L.). Enhanced leaf chlorophyll content following MLE and ANE application, could possibly be due to enhanced gene transcripts involved in photosynthesis, cell metabolism and stress response. Application of ANE and MLE suppresses cysteine protease activity [17], which ultimately results in the inhibition of chlorophyll degradation, thus, delaying senescence in plants (Table 1).

In addition, ANE and MLE contain several antioxidant compounds, including ascorbic acid, tocopherols, flavonoids and polyphenol ; their presence triggers antioxidant biosynthesis, thereby reducing stress caused by reactive oxygen species (ROS) [18]. These ROS can cause cell and membrane degradation, hence, the antioxidant compounds found in ANE and MLE could promote growth and developmental processes by reducing ROS levels in potato plants [19]. Rioux et al. [20] reported that, besides containing minerals, plant hormones and antioxidant compounds, *Ascophyllum nodosum* extract can exhibit a wide range of growth- and yield-stimulatory effects because of the polysaccharides present in the extract. Such compounds include laminarin [β-glucan – (β-D-glucose polysaccharide)] and fucoidans (fucose-rich sulphated polysaccharides, consisting primarily of 1,2-linked a-L-fucose-4-sulfate units with very small amounts of D-xylose, D-galactose, D-mannose, and uronic acid), both exhibiting radical scavenging antioxidant activity[20]. Rayorath et al. [15] reported significant amounts of betaine (trimethylgycine, a non-protein, methyl-derivative of glycine) present in ANE; which plays a significant role in counteracting metabolic dysfunctions brought on by stress; thus, improving plant growth and productivity.

Improved vegetative growth (e.g., plant height, number of leaflets, leaves and leaf area), certain physiological (leaf chlorophyll index) and yield (tuber yield and mass) attributes following plant extract applications (Table 1) are, therefore, in line with Haider et al. [9], who demonstrated a significant improvement in growth and yield attributes of potatoes due to various ANE treatments. Similarly, Rajendran et al. [10] demonstrated that growth and yield parameters, such as plant height, number of leaves and leaf area of sweet pepper plants were significantly enhanced by foliar ANE and MLE application. In addition, ANE and MLE applications to tomato plants grown under water-deficit conditions significantly improved plant height, number of leaves and branches, as well as leaf area [11]; these findings correspond well with the present study. Various authors also reported considerable increase of leaf chlorophyll index following ANE foliar application in several crops, such as broccoli (*Brassica oleracea* var. *italica*) [21] and okra (*Abelmoschus esculentus* L)[22], these findings coincide with the present research.

5. Conclusion

The present study yet encourages the use of various plant extracts in the crop farming community. The pre-harvest foliar application of various plant extracts considerably enhanced vegetative growth, physiological and yield attributes of potato. Since modern agriculture necessitate financially feasible and easily accessible organic inputs, use of plant extracts, as biofertilizers, biostimulants and bio-elicitor could effectively be used as an ideal multi-active organic input to improve crop growth and yield potential of agricultural crops. This research has shown that foliar applications of plant extracts, especially of ANE and MLE, have the potential to improve crop productivity and yield. Results presented in this study are, hence, of high significance to commercial as well as small-scale potato growers, as use of organic plant extracts is an environmentally friendly and a sustainable approach towards increasing crop productivity. Plant extracts have shown beneficial effects on solanaceous crops, but further validations of these effects on other crops is recommended.

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