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Corchorus olitorius: A Promising Medicinal Plant in Southern Africa and Effects of Growing Conditions on Its Bioactive Compounds—A Review

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Abstract

Corchorus olitorius (Jew's mallow), is one of the African indigenous leafy vegetables increasingly getting attention as a possible contributor of both micronutrients and bioactive compounds including proteins, lipids, fiber and vitamin C to human nutrition. Leaves of *Corchorus olitorius* have been found to have high level of phytochemicals: flavonoids, polyphenols, tannins, and saponins that possess strong radical scavenging activity and antioxidant power. In the arid and semi-arid areas of the world, drought is the main limiting factor affecting plant productivity and influences almost all aspects of plant biology. Water stress deficit is known to cause oxidative stress condition that has generally been reported to elevate phenolic antioxidants in various crops including Jew's mallow. On the other hand, fertilization is crucial for crop management and high yield, it also affects nutritional value of the food plants. Nitrogen (N) fertilization affects health and nutritional value, including mineral content, fatty acid profile, anti-oxidative capacity and polyphenol levels and composition. The possible effects of fertilization should be considered when deciding on fertilization regime, to optimize both plant physiology, productivity and food-related effects. Nitrogen is an important element for Jew's mallow production since it responds well to it. However, appropriate amounts of nutrients need to be provided to crops at the right time to favor both crop growth, yield and quality. Different reports confirmed that addition or increase of N, negatively affects the total phenolics and total flavonoids, and reduces accumulation of defense-related secondary metabolites resulting in lower oxidative capacity. Increased secondary metabolite production during water deficit and low nitrogen in the soil has been reported as a stress mechanism by most plants. However, further research is required to explore the biochemical response of Jew's mallow to water deficit and nitrogen fertilization.

Keywords

Jew's Mallow, Nitrogen, Antioxidants, Drought, Minerals

1. Introduction

The genus Corchorus consists of some 50-60 species, of which about 30 are found in Africa [1]. Corchorus is mainly known for its fibre product jute and for its leafy vegetables [2]. Jute is mainly extracted from *Corchorus olitorius* L. and *Corchorus capsularis* L., a species from India. Several species of Corchorus are used as a vegetable, of which *Corchorus olitorius* L is most frequently cultivated. *Corchorus olitorius* L is basically self-pollinating, but levels of 10% - 13% outcrossing have been reported [3] [4]. Deliberate crossing by hand was found to be particularly difficult due to flower drop after emasculation. Natural crossings are found, but these are rather difficult to control.

Jew's mallow, is one of the African indigenous leafy vegetables increasingly recognized as a possible contributor of micronutrients and bioactive compounds [5]. Nutritionally, *Corchorus olitorius* leaves are rich in beta-carotene, iron, calcium, fiber, vitamin C, A, E, proteins, sodium and folic acid [6]. Indigenous leafy vegetables contain ascorbic acid which enhances iron absorption and is compatible for use with starchy food [7]. Jew's mallow has been perceived as a valuable source of nutrition in rural areas in addition to adding diversity to diet. Therefore, there should be inclusion of indigenous leafy vegetables in the diet to overcome various deficiencies. Interestingly, exotic vegetables such as cabbage are reported to have minerals and vitamins lower than those found in indigenous leafy vegetables [6].

African edible species of Corchorus are annual or short-lived perennial crops, up to 2 m high. Their stems are well developed with abundant fibers in the phloem tissue, which is why they are also used as fiber crops [8]. It is an annual or biennial herb, erect, stout, strongly branched, that varies in height from 0.20 to approximately 2 m, depending on the genotype. The stems of Jew's mallow are angular with simple oblong to lanceolate leaves measuring 5 to 15 cm in length. These leaves have a long, acuminate tip and a serrated or lobed margin. The flowers are small, 2 to 3 cm in diameter and yellow, with five petals. The flowers have both male and female organs and are pollinated by insects [9]. The fruit of Jew's mallow is globular while some were reported to be long [10] [11].

1.1. Geographical Distribution and Climatic Requirements

Jew mallow is native to tropical and subtropical regions, the origin of Jew's mallow is reportedly unknown, but has reportedly been cultivated for centuries, in

Asia and Africa [2], It occurs in the wild on both continents. Because of the much wider diversity within this species in Africa and the occurrence of several related species in Africa, an African origin for *Corchorus olitorius* is more likely [9]. Throughout the world *Corchorus olitorius* is a vegetable eaten in both dry and semi-arid regions and in the humid areas of Africa. It has been largely produced as a very important vegetable in arid regions of the Middle East and Africa. It is an important green leafy vegetable in many countries including Egypt, Southern Asia, Japan, India, China, Lebanon, Palestine, Syria, Jordan, Tunisia and Nigeria. It is a leading leafy vegetable in Côte d'Ivoire, Benin, Nigeria, Cameroon, Sudan, Kenya, Uganda and Zimbabwe. It is also cultivated as a leafy vegetable in the Caribbean, Brazil, India, Bangladesh, China and the Middle East [9] [12] [13]. It is cultivated for fiber in Asia (India, Bangladesh and China).

Climatic Requirements

Jew's mallow needs alluvial soil and well drained fertile soils, clay soils are not suitable [9]. It tolerates a pH ranging from 4.5 to 8.2 [12]. Temperatures from 20˚C to 40˚C and relative humidity of 70% - 80% are favorable for successful cultivation, and more during the sowing period. The optimum temperature is 25˚C to 32˚C, where temperatures below 15˚C are detrimental to the crop. It cannot grow in the shade and the crop performs well in areas with rainfall of between 600 and 2000 mm/year. Jew's mallow is susceptible to drought at different stages of growth and especially during the flowering stage. High vegetative yields can therefore be obtained with increases in water application. It requires moist soil, but cannot tolerate waterlogging. Corchorus species appear to be able to adapt themselves to harsh conditions [9].

1.2. Nutritional Importance of Jew's Mallow

Jew's mallow, is one of the African indigenous leafy vegetables increasingly recognized as a possible contributor of both micronutrients and bioactive compounds [5]. Nutritionally, *Corchorus olitorius* leaves are rich in beta-carotene, iron, calcium, fiber, vitamin C, A, E, proteins, sodium and folic acid [6]. It has been perceived as a valuable source of nutrition in rural areas in addition to adding diversity to diet. Therefore, there should be inclusion of indigenous leafy vegetables in the diet to overcome various deficiencies. Interestingly, the exotic vegetables such as cabbage are reported to have minerals and vitamins lower than those found in indigenous leafy vegetables [6]. **Table 1** below summarizes the reported nutritional value of Jew's mallow leaves from different accessions and varieties.

1.3. Phytochemical/Bioactive Compounds in Plants

Phytochemicals are defined as bioactive compounds/ chemicals in fruits, vegetables, grains and other plant foods that may provide sensible health benefits past basic nutrition to minimize the chances of major chronic disease infections [26]. Among them are the polyphenols, flavonoids, isoflavonoids, terpenoids, caretonoids, anthocyanidins, phytosterol and fiber and they are antioxidants rich phytochemicals [27]. Bioactive compounds have great antioxidant capability and are of great interest to their beneficial effects on health of humans. Epidemiological trials suggest that the regular consumption of fruits, vegetables and whole grain reduce the risk of various diseases linked with oxidative damage [28]. Free radical scavenger acts as hydrogen donors, electron donor, peroxide decomposer, enzyme inhibitor and singlet oxygen quencher. The protective role of phytochemicals may be associated with their antioxidant activity since overproduction of oxidants (Reactive Oxygen Species and Reactive Nitrogen Species) in human body is involved in the pathogenesis of many chronic diseases [29]. These phytochemicals are classified as primary and secondary constituents depending on their role in plant metabolism [27]. Primary metabolites include chlorophyll, common sugars, amino acids, proteins, purines, while secondary metabolites include alkaloids, flavonoids, tannins, proine lipids, terpenes, phenolics, carbohydrates. Antioxidants are secondary metabolites.

Table 1. Nutritional value of *Corchorus olitorius* leaves.

Leaf mass used	Moisture%	Energy (Cal)	Proteins (g)	Fibre (g)	Carbohydrate (g)	Ash (g)	Ca (mg)	P (mg)	Fe (mg)	Na (mg)	K (mg)	Vit A	Vit C	Authors
100 g	80 - 84.1	43 - 58	4.5 - 5.6	1.7 - 2	7.6 - 12.4	2.4	266 - 366	97.12	11.6	12	444	6.39	95	[14] [15]
10 g	11.31 - 18.18	-	50.59 - 62.96	-	6.72 - 17.94	4.42 - 8.82	3.52 - 11.17	-	-	-	-	-	-	[16]
100 g	14.3	-	1.26%	33.61%	0.03	-	-	-	-	-	-	-	-	[17]
100 g	-	-	-	-	-	-	1.2 - 1.31%	-	0.02% - 0.051%	0.32% - 0.51%	2.08% - 3.10%	-	-	[18]
100 g	10.2	117.2	22.1	12.3	42.2	10.8	33.3	2.67	4.15	21.8	28.3	-	-	[19]
100 g	-	200.78	12.54	-	19.56	18.36	30.55	6.68	19.53	54.56	281.15	-	-	[20]
100 g	83	55	5.6	1.9	12.4	2.3	365	99	11.5	12	444	-	53 - 80	[21]
100 g	-	-	162.20	20.30	695	105.20	0.347	0.258	0.228	-	-	-	-	[22]
100 g	-	-	4.8 - 6	1 - 5	5	-	259 - 269	-	4.5 - 8	-	-	7.7	101	[23]
100 g	-	-	4.8	-	-	-	259	-	4.5	-	-	4.7	105	[24]
100 g	10.06	1.53	28.83%	7.36%	-	12.01%				-	-	-	-	[25]

Plant secondary metabolites are unique sources for pharmaceuticals, food additives, flavors, and industrially important biochemical. Accumulation of such metabolites often occurs in plants subjected to stresses including various elicitors or signal molecules [30]. Secondary metabolites play a significant role in the adjustment of plants to the environment and in overcoming unfavorable conditions. Environmental factors such as temperature, humidity, light intensity, the supply of water, minerals and CO_2 influence the growth of a plant and secondary metabolite production. Drought, high salinity and freezing temperatures are environmental conditions that cause unfavorable effects on the growth of plants and the productivity of crops.

2. Bioactive Compounds and Antioxidant Activity of *Corchorus olitorius* Plant

Corchorus olitorius leaf is used as folk medicine in Jew's mallow farming communities possibly because it has been reported to be rich in secondary metabolites [31]. It has been reported that different chronic diseases like obesity, diabetes, tumors and cardiovascular diseases are well managed by Jew's mallow and can halt their progression [31]. It was found that these plants are good dietary source of some phytochemicals such as tannins, flavonoids, and other polyphenolics [32]. Secondary metabolites such as phenolic compounds in plants manifest a wide range of physiological properties, such as anti-inflammatory, cardio protective, antioxidant, anti-allergenic, anti-microbial, anti-atherogenic, anti-thrombotic and vasodilatory effects [29]. In Europe, Jew's mallow was introduced as a functional food because of the phytochemicals that are present in its leaves [33]. These essential compounds accumulation in plant leaves is associated with photo-inhibition and photo-respiration in particular. Public health care is still a great challenge for the population in developing countries which are still mostly in the marginal income bracket, where the use of food as an alternative source of health intervention is still very critical. Therefore, improvement of this important indigenous leafy vegetable becomes more remarkable because of its wide utilization among the population.

Corchorus olitorius leaves possess an abundance of minerals, antioxidant compounds associated with various biological properties, which include diuretic and antimicrobial activities, antitumor and phenolic anti-oxidative compounds, anti-obesity and gastro-protective [34]. Different experiments have shown that plant parts, such as roots, barks, leaves and seeds, of *Corchorus olitorius* contain flavonoids, cardiac glycosides, fatty acids, triterponoids, polysaccharides and phenolics [35] [36] [37] [38]. Secondary metabolite molecules in plant foods associated with various biological activities are present in the leaves of *Corchorus olitorius*; these include high levels of tannins, flavonoids, saponins and polyphenols that possess strong antioxidant power and radical scavenging activity.

These bioactive compound concentrations are strongly dependent on genotypes [39]. The curative potential and nutritional values of the Jew's mallow leaves have led to studies on antioxidant potency and chemical content of the leaves in order to find promising new sources of natural antioxidants. Research with newly isolated compounds has shown that *Corchorus olitorius* leaves possess high levels of antioxidants and microbial activities [40]. These polyphenolics compounds can directly contribute to antioxidant actions within a cell and have come to be attractive natural ingredients in the pharmaceutical and cosmetic industries because they are excellent electron donors and possess distinctive beneficial biological properties [41]. Certain tannins have been shown to inhibit human immune deficiency virus (HIV) replication because of their therapeutic properties hence tannins being used in the treatment of different diseases to boost human health. Nevertheless, research about the phytochemical constituents of Jew's mallow genotypes ought to assist in developing an extended perception and understanding of the medicinal and nutraceutical value of Jew's mallow, which in turn could enhance its consumption. In addition, there is a need to understand how this plant bioactive compounds respond to water deficit which is common in semi—arid areas, not only that, even the nitrogen fertilization but because of the commonly poor soils especially in N and P.

The aspect of a quality in medicinal plants including indigenous vegetables such as *Corchorus olitorius* is very important [42]. Quality of the product is determined by the presence of secondary metabolites such as saponins, alkaloids, tannins, steroids, phenolic compounds in plants. The qualitative and quantitative determination of secondary metabolites in various parts of the plant can be influenced by managing factors or farming practices [43]. Secondary metabolites like flavonoids have a special role in determining plant quality because they contribute to the color and flavors of vegetables and fruits and may have high antioxidants level that help protect human from degenerative diseases. Secondary metabolite molecules in plants food are attributed to various biological activities, the present and definitive findings demonstrate that leaves of *Corchorus capsularis* and *Corchorus olitorius* with the high level of phytochemical constituents include flavonoids, polyphenols, tannins, and saponins that possess strong radical scavenging activity and antioxidant power [38]. Similar conclusions were drawn for Principal Component Analysis (PCA) or Hierarchical Cluster Analysis (HCA) based on data sets. Based on the HCA and PCA, 30 populations belonging to *Corchorus capsularis* and *Corchorus olitorius* effectively formed five distinct groups. Results showed that bioactive compounds, especially flavonoids, polyphenols, and total tannins were detected. Therefore, some accessions could serve as elite material for facilitating breeding strategies to supply a promising potential as an outstanding source of natural antioxidants in food, pharmaceutical, and cosmetics industry. The presence of different phytochemicals including cholesterol, alkaloids, phenols, riboflavin, saponins, flavonoids, terpenoids, tannins, glycosides [44] was demonstrated. In addition to that, the samples also proved antioxidant activity by inhibiting DPPH radical. It has been demonstrated that the antioxidant effect of plant products is mainly due to radical scavenging activity ability of phenolic compounds such as flavonoids, tannins, phenols and alkaloids [45].

[46] reported that, the methanolic extract of *Corchorus olitorius* exhibited good antioxidant and antidiabetic potential and polyphenols were proven to be responsible for the antioxidant and antidiabetic effects. The qualitative phytochemical determination showed the presence of saponin, glycosides, gum, tannin, phenolic compounds, where the total phenolics and total flavonoids were expressed in terms 0.3 - 0.07 mg GAE per gram equivalents. Furthermore, they reported the half maximal inhibitory concentration (IC_{50}) values of the DPPH radical scavenging activity as 37.65 $\mu g \cdot mL^{-1}$. Plants containing phenolics and flavonoids class of compounds are reported to possess excellent antioxidant activity [47]. In another study by [48], they reported that, the antioxidant effect of

the aqueous extract of *Corchorus olitorius* may be attributed due to its higher TPC, TFC and ascorbic acid content. Therefore, the presence of medicinally important metabolites in different parts of *Corchorus olitorius* justifies its use in different health disorders treatment [49] including diabetes mellitus [50].

Furthermore, the phenolic index revealed significant differences in total polyphenols among the accessions of *Corchorus olitorius*. The highest values of polyphenols were measured in accession from India and Japan, with absorbance values of 54.2 and 58.31 ABS320nm g^{-1} FW, respectively [33]. The lowest values were measured in the accessions from China and Libya, with values of 24.1 and 20.1 ABS320nm g^{-1} FW, respectively. Moreover, the same trend was found for the phenolic content (Gallic Acid Equivalent) in the leaves. Carotenoid and chlorophyll levels in *Corchorus olitorius* leaves changed significantly between different accessions. In fact, the amount of carotenoids in *Corchorus olitorius* leaves changed in correlation with chlorophyll according to their physiological action of supplementary pigments. Despite this correlation, significant differences in carotenoid content among the accessions were less pronounced than those for chlorophyll.

The increase in secondary metabolites and antioxidant activity may be caused by the presence of various major (i.e. nitrogen, potassium and phosphorus) and minor elements in organic fertilizers and inorganic fertilizers [51]. High nutrient availability leads to an increase in plant growth and development, but it reduces the allocation of resources to produce secondary metabolites [52]. Macronutrients have a significant effect on plant growth and polyphenols and antioxidants accumulation [53]. Among the major nutrients nitrogen is the most important element in plant nutrition and is a primary plant nutrient to achieve maximum yield in crop [54]. In addition, nitrogen nutrition influences both the primary and secondary metabolic pathways thus secondary plant metabolites accumulation [55]. It has been reported that drought affects the secondary metabolites [56]. Drought stress triggers downstream pathway such as phyto-hormone homeostasis and their signaling pathways, consequently this initiates the biosynthesis of different types of protective secondary metabolites. They provide multi-stress tolerance including abiotic and biotic stresses.

2.1. Response of *Corchorus olitorius* Bioactive Compounds to Water Deficit Growing Conditions

Drought is one of the factors influencing almost all aspects of plant biology and productivity in the arid and semi-arid areas of the world [57]. Despite the good nutritional quality and medicinal values of Jew's mallow, its production is limited to the rainy season. In drought conditions, soil becomes dry and drought stress is perceived through roots as a stress signal through cell-to-cell signaling networks [56]. These stress signals subsequently travel to the leaves through the roots to shoot signaling via xylem to induce the systemic phyto-hormone signaling and secondary metabolites biosynthesis. Recently, there has been an increasing interest in various elicitors employed to induce the synthesis of secondary metabolites [58]. Environmental stresses especially water stress have been considered as the main factor responsible for the elevated metabolites content in plants [59]. Water deficit or osmotic stress leads to increased formation of Reactive Oxygen Species (ROS) which can be detrimental to cellular components at high concentrations. ROS damage membrane, increases malondialdehyde (MDA) content, alters activities of antioxidant enzymes, photosynthetic apparatus, different functional elements of plants. On the other hand, antioxidants, both enzymatic (peroxidases, superoxide dismutase, catalase) and non-enzymatic (phytochemicals) play a defense role in diminishing the activities of the free radicals in plants [60]. Plants increase the activities of antioxidants enzymes which is considered as one of the abiotic stress tolerance strategies in plants [61].

Included among secondary metabolites with a high antioxidant capacity are polyphenols/flavonoids compounds that have since received an increasing attention not only for their beneficial effects on human health but also for the protection they provide against oxidative injury in plants under abiotic stress [62]. Increased polyphenols and flavonoids have been reported in response to water deficit [63]. Water stress deficit is known to cause oxidative stress condition that was generally reported to elevate phenolic antioxidants in various crops [64].

A significant elevation of polyphenols concentration in the tolerant genotypes of *Corchorus olitorius* following water deficit stress as compared to control group [65] was reported, however the total flavonoids content was decreased significantly. The susceptible genotypes were found to produce significantly increased flavonoids concentration as compared to water deficit stress tolerant genotypes following progressive water stress treatment. Interestingly, the susceptible genotypes were found to have significantly reduced polyphenols content after a progressive water deficit stress. These results were in agreement with the other reports findings where it was reported that, depending upon the species genotype and cultivar, the level of these antioxidants varied following the water deficit stress in different crops [66] [67] [68]. This signifies the dynamic role of polyphenols and flavonoids towards stress adaptation of *Corchorus olitorius* genotypes subjected to prolonged water deficit stress. In addition, *Corchorus olitorius* has been reported rich in several polyphenols and their amount and composition are not modified by stressful cultivation conditions such as reduction in water irrigation [69]. Generally, environmental stressors such as osmotic stress due to water scarcity, may be able to elicit the production of secondary metabolites in the leaves as it happens in the case of amaranth [70] and *Corchorus olitorius* itself although these species were found to greatly vary in its responses depending on the genotype [65]. In contrary, [61] observed that, *Corchorus olitorius* responded differently under different abiotic stress including drought, salinity, temperature, waterlogging, heavy metals amongst them. Severe oxidative damage and ion leakage were recorded in drought stress compared to other stress. However, at severe water logging stress, there was upregulation of antioxidant enzyme activities compared to other stresses. **Table 2** below summarizes findings on response of *Corchorus* species to different abiotic stress factors.

Table 2. Response of *Corchorus* species and other plants' bioactive compounds to some abiotic and water deficit stress related factors.

Water deficit related stress factor	Findings	Authors
Salinity on the *Corchorus olitorius*	Reduced total tannins by 1.3% while the phenolic compounds increased by 6% as well as the proline content.	[71]
Salinity on *Corchorus spp*	Increasing trend in melondialdehyde (MDA) with an increase in salinity	[72]
Water deficit on *Corchorus capsularis*	An increased hydrogen peroxide content was observed upon exposure to water deficit condition.	[73]
Heavy metal on *Corchorus capsularis*	Increased activity of a scorbate peroxidase (APX) seedlings at different levels of copper stress due to overproduction of reactive oxygen species (ROS) was observed.	[74]
Water deficit on *Solanum villosum*	Water deficit increased the phenolic content and the total antioxidants by 52.68%.	[75]
Drought on A. cruentus accessions	Flavonoids of the selected species and accessions were not significantly influenced by drought, only the total phenolic acid significantly increased with increasing drought stress.	[76]
Water deficit on lettuce	Only one cultivar among others responded to different water regime through increasing phenolic compounds.	[77]
Water deficit on olive tree	Elevated values of phenolic compounds were reported to be a well-known mechanism in the olive trees against water deficit.	[78] [79] [80]
Reduced irrigation on basil	Flavonoids and phenolic compounds increased under drought stress where they had higher amount under reduced irrigation than normal irrigation.	[81]
Water deficit on pea varieties	Significant increase in total flavonoids concentration was detected across all three pea varieties under severe stress condition.	[82]
Water deficit on *Solanum lycopersium*	At 60% field capacity, the MDA content increased by 83%.	[83]

It is therefore sensible to conduct empirical studies on every economically important species to establish the influence of water deficit on final market produce, this is due to the remarkable variability in the influence of moisture stresses on the physiological and nutritional qualities of different crop species including *Corchorus olitorius*. Further studies are required to explore the biochemical and genetic response of *Corchorus* species under water deficit which will be helpful for understanding the tolerance mechanisms as it has been studied with other plants.

2.2. Response of Plant Bioactive Compounds to Nitrogen Fertilization

Nitrogen nutrition plays a major role not only in plant growth and yield determination but also in quality composition. Nitrogen fertilizer usage in crop production significantly enhances not only plant growth but even crop quality [84].

However, when fertilizer is used, amounts are very variable due to variation of nutrients in the soil and farmers need to establish rates that are most economical for their production purpose. Nitrogen is an important element for Jew's Mallow production since it responds well to it [85]. Therefore, appropriate amounts of nutrients need to be provided to crops at the right time to favor both crop growth, yield and quality. Both the primary and secondary metabolism of higher plants is influenced by mineral nutrition [86]. Species growing in nutrient-poor habitats often have traits that lead to high nutrient retention and high levels of secondary metabolites [87] but the effect is species dependent. Deficiency in mineral elements such as nitrogen, phosphorous and potassium have been reported to up-regulate the amounts of polyphenols either as existing pools or by inducing their *de novo* synthesis [88]. [89] observed an increased amount of flavonoids as a consequence of phosphorus and water limitation. **Table 3** summarizes response of some medicinal plants to nitrogen fertilization. However, response of *Corchorus olitorius* bioactive compounds to nitrogen fertilization is under-researched.

Table 3. Effects of nitrogen fertilization (soil nutrition) on medicinal plants bioactive compounds.

Nutrition effect on specific plant	Findings	Authors
Nitrogen application on *Allium fistulosum*.	Total phenolic content increased to highest level of 22.66 mg GAE/g DW at 260 kg N/ha with no significant difference between control and 130kg N/ha application. Total flavonoids content (760 mg/g DW highest in samples of 130 kg N/ha.	[90]
Nitrogen application on *Camellia sinensis*	Nitrogen deficiency and excess nitrogen have inhibitory effect on biosynthesis of flavonoids.	[91]
Nitrogen application on *Allium fistulosum*	Flavonoids content was not significantly different after treatment with high or low levels of nitrogen fertilizer and was concluded that N may be able to increase flavonoids at certain concentration beyond which no further accumulation can be induced.	[92]
Nitrogen application on *Cynara scolymus* L.	200kg N/ha application improved the growth but significantly reduced total phenols, total flavonoids, antioxidant activity.	[93]
Nitrogen application on *Labisia pumila Blume*	High amounts of nitrogen decreased the production of secondary metabolites. Production of the total flavonoids and total phenols reached their peak at control followed by 90kg N/ha and this increase in production under low nitrogen correlated with enhanced phenylalanine lyase activity.	[94]
Nitrogen on strawberry	Biosynthesis of secondary metabolites was stimulated by nitrogen deficiency and it was found that flavonoids and phenols were crucial factors in determining the antioxidant activity of this plant.	[95]
Nitrogen application on *Chrysanthemum morifolium*	Heavy nitrogen fertilization decreased antioxidant activity of the flower	[96]
Nitrogen application on *Java cardamom*	There was no significance difference at all levels of control, 9 and 1.3 g N/polybag where the highest total phenols were reported on the highest level but was not significantly different from other levels.	[97]

Continued

Nitrogen application on green cardamum	The highest total phenolic content was observed on treatment without nitrogen fertilizer at 33.45 mg GAE/g DW.	[98]
NPK application on *Solanum muricatum* Aiton.	An increase in NPK fertilizer rate led toan increase in metabolites up to 200kg/ha after which contents decreased. The control favoured the accumulation of total phenolic content. At 400 kg/ha rate, phenolic content decreased in both growing environment.	[99]
Nitrogen forms application on Amaranth plant	Sole $NH4^+$ induced stress enhanced total flavonoids, phenolics and natural antioxidants with effective antioxidative capacity; a striking metabolic plasticity observed during plant growth and survival trade-off in vegetable amaranth.	[100]
Nitrogen application on sweet basils	Synthesis of secondary metabolites was stimulated by nitrogen deficiency and this enhanced the accumulation of the total phenolic content.	[101]
Nitrogen application on ripe pepino fruits	The phenolic content increased under the control treatment	[102]
Nitrogen applicant on *Vitex negundo* Linn	The nitrogen treated showed an enhanced total flavonoid at a low nitrogen fertilization but the content decreased with increasing nitrogen fertilization. The total phenolic content in nitrogen treated was not significantly different from the control.	[103]
Nitrogen application on *Subaratic tundra*	Nitrogen addition reduced the condensed tannins and the total phenolic content	[104]
Phosphorous application on nightshade	Elevated total phenolic and antioxidant activity in black nightshade	[105]

The effects of N fertilization on the biosynthesis of polyphenols have been reported to be dependent on species [106]. In general, increasing N fertilization increases the biomass production, but may cause a reduction in the concentration and yield of secondary metabolites. The negative effect of nitrogen on phenol concentration can possibly be attributed to competition of phenylalanine which can be used in phenolic synthesis [107]. Phenylalanine is a precursor in the biosynthesis of phenolic. Therefore, there might be a competition for phenylalanine between protein synthesis and secondary metabolites synthesis. Hence biosynthesis of secondary metabolites might be inhibited due to incorporation of phenylalanine into protein synthesis. Its gene expression increases under N depletion [107]. However, effects of nitrogen fertilization on bioactive compounds of Jew's mallow have not been exploited like other crops which give researchers the opportunity to research the plant response to nitrogen fertilization.

Generally, plants growing in nitrogen poor condition are thought to contain more secondary metabolites compounds than plants growing in a nitrogen rich environment possibly because, in high nitrogen available nutrient environment, large amounts of carbohydrates are allocated to primary metabolism (protein metabolism) while secondary metabolites are limited. Inversely, primary and secondary metabolism competes for available assimilates and there is a trade off in the Carbon allocation. That is the possible reason photosynthesis is less sensitive to N limitation than growth, implying that carbohydrates accumulations can exceed growth demand resulting in the C atom availability for conversion in carbon based secondary metabolites. This is because when growth is limited, the accumulated carbohydrates-carbon atom will be converted to metabolites. These effects of nitrogen on plants should be well considered when deciding on the fertilization regime, to optimize both plant physiology, productivity and food related effects. But there has not been exploitation on how the different levels of nitrogen affects the antioxidants of Jew's mallow as the water deficit effects on the bioactive compounds.

3. Conclusion and Recommendations

Water and nitrogen are two major limitations in crop production. Abiotic stresses like drought and mineral nutrition are commonly interconnected through some physiological elicit in stressed plants, such as synthesis of protective plant compounds as a response to stress. Many of these are produced within plant primary and secondary metabolism, as a functional compound not exclusively in plants, but even in other organisms as well. Many of the bioactive compounds in bio-stimulants can support plant stress tolerance and productivity in adverse growth and it is the metabolites that can influence the plant's edible part quality. An understanding of the genetic and physiological basis of drought tolerance would facilitate the development of improved crop management and breeding techniques and lead to better yield in unfavorable environments including the N response. Their tolerance to water-limited conditions is a complex phenomenon that involves specific morphological and developmental mechanisms with physiological change. It is therefore concluded that *Corchorus olitorius* showed to be a promising plant for improving health benefits and agricultural sustainability due to the great number of antioxidant compounds in leaves, whose occurrence is not altered by stressful farming conditions due to its adaptability possibly as a survival mechanism strategy, by increasing antioxidants contents. However, the water deficit response on *Corchorus olitorius* has been exploited while the nitrogen fertilization response on bioactive compounds has not been fully exploited which requires further investigation. Because of the existing gap on the effects of growing conditions on its bioactive compounds, it is recommended that studies be conducted to explore the nitrogen nutrition as well as the interaction of the water deficit and nitrogen nutrition on the bioactive compounds concentration.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] Chweya, J.A. and Eyzaguirre, P.B. (1999) The Biodiversity of Traditional Leafy Vegetables. International Plant Genetic Resources Institute.

[2] Schippers, R.R. (1996) Domestication of Indigenous Vegetables for Sub-Saharan Africa. Technical Report, Natural Resources Institute Project A0515, Natural Resources Institute, Chatham.

[3] Grubben, G.J.H. (1977) Leaf Vegetables. Tropical Vegetables and Their Genetic Resources. International Plant Genetic Resources Institute.

[4] van Epenhuijsen, C.W. (1974) Growing Native Vegetables in Nigeria. FAO.

[5] Mavengahama, S., de Clercq, W.P. and McLachlan, M. (2015) Effect of Soil Amendments on Yield of Wild Okra (*Corchorus olitorius*) in Northern Kwazulu-Natal, South Africa. *South African Journal of Plant and Soil*, **33**, 153-156. https://doi.org/10.1080/02571862.2015.1090023

[6] Maseko, I., Ncube, B., Mabhaudhi, T., Tesfay, S., Chimonyo, V.G.P., Araya, H.T., *et al*. (2019) Nutritional Quality of Selected African Leafy Vegetables Cultivated under Varying Water Regimes and Different Harvests. *South African Journal of Botany*, **126**, 78-84. https://doi.org/10.1016/j.sajb.2019.06.016

[7] Nesammvuni, C., Steyn, N.P. and Potgierter, M.J. (2001) Nutritional Value of Wild Leafy Plants Consumed by the Vhavenda. *South African Journal of Science*, **97**, 51-54.

[8] Denton, L. (1997) A Review of *Corchorus olitorius* in Nigeria. *Proceedings of a Workshop on African Indigenous Vegetables*, Limbe, 13-18 January 1997, 25-30.

[9] Schippers, R.R. (2000) African Indigenous Vegetables: An Overview of the Cultivated Species. Natural Resources Institute/ACP-EU Technical Centre for Agricultural and Rural Cooperation, 214.

[10] Ngomuo, M., Stoilova, T.S., Olayinka, B.N., Lateeef, A.A., Garuba, T., Olahan, G.S., Tiamiyi, B.B. and Abdulrahman, A.A. (2017) Molecular Characterization of Some Accessions of *Corchrous olitorous* L.*Savanna Journal of Basic and Applied Sciences*, **1**, 213-217.

[11] Arlette, A., Estelle, L.Y.L., Zaki, B., Donald, B., Tiburce, O., Hounnankpon, Y. and Alexandre, D. (2019) Agromorphological Characterization of Jute (*Corchorus olitorius* L.) Landraces in Central Region of Benin Republic. *International Journal of Advanced Research in Biological Sciences*, **6**, 96-107.

[12] Fawusi, M.O.A. and Ormrod, D.P. (1981) Effects of Temperature on the Growth of *Corchorus olitorius*. *Journal of Horticultural Science*, **56**, 353-356. https://doi.org/10.1080/00221589.1981.11515012

[13] Samra, I., Piliz, S. and Ferdag, C. (2007) Antibacterial and Antifungal Activity of *Corchorus olitorius* L. (Molokhia) Extracts. *International Journal of Natural and Engineering Sciences*, **1**, 59-61.

[14] Islam, M.M. (2010) In: Jute (in Bengali Version), Pub. Dynamic Publisher.

[15] Islam, M. (2013) Biochemistry, Medicinal and Food values of Jute (*Corchorus capsularis* L. and *Corchorus olitorius* L.) Leaf. *International Journal of Enhanced Research in Science Technology & Engineering*, **2**, 35-44.

[16] Osawaru, M.E., Ogwi, M.C. and Aiwansoba, R.O. (2015) Hierarchial Approaches to the Analysis of Genetic Diversity in Plants: A Systematic Overview. *University of Mauritius Research Journal*, **21**, 1-36.

[17] Osei-Owusu, J., Kokro, K.B., Ofori, A., Apau, J., Dofuor, A.K., Vigbedor, B.Y.,

Aniagyei, A., Kwakye, R., Edusei, G., Antwi, B.Y. and Okyere, H. (2023) Evaluation of Phytochemical, Proximate, Antioxidant, and Anti-Nutrient Properties of *Corchorus olitorius*, *Solanum macrocarpon* and *Amaranthus cruentus* in Ghana. *International Journal of Biochemistry and Molecular Biology*, **14**, 17-24.

[18] Islam, M., Ali, S. and Gani, N. (2018) Assessment of Soil Fertility, Fibre Production, Nutritional and Medicinal Value of Jute Leaves as Affected by Indigenous Organic Matters Management. *Journal of Nutrition and Food Science Forecast*, **1**, 1007.

[19] Adesina, A.J., Olaleye, A.A., Popoola, O.K., Olatunya, A.M., Gbolagade, A.Y., Idowu, K.A. and Ajakaye, A.O. (2022) Nutritional Evaluation of Leafy Vegetables of *Corchorus olitorius* Family from Ekiti State, Nigeria. *ChemSearch Journal*, **13**, 147-156.

[20] Idirs, S., Yisa, J. and Ndamitso, M. (2010) Nutritional Composition of *Corchorus olitorius* Leaves. *Animal Production Research Advances*, **5**, 1-5. https://doi.org/10.4314/apra.v5i2.49827

[21] Rume, J.M. (2010) Phytochemical, Antimicrobial and Biological Investigations of Methanolic Extract of Leavrs of *Corchorus capsularis*. Master's Thesis, East West University.

[22] Ndlovu, J. and Afolayan, A.J. (2008) Nutritional Analysis of the South African Wild Vegetable *Corchorus olitorius* L. *Asian Journal of Plant Sciences*, **7**, 615-618. https://doi.org/10.3923/ajps.2008.615.618

[23] Choudhary, S.B., Sharma, H.K., Karmakar, P.G., Saha, A.R., Hazra, P. and Mahapatra B.S. (2013) Nutritional Profile of cultivated and Wild Jute (*Corchorus*) Species. *Australian Journal of Crop Science*, **7**, 1973-1982.

[24] Grubben, G.J.H. and Denton, O.A. (2004) Plant Resources of Tropical Africa 2. Vegetables. Plant Resources of Tropical Africa Foundation.

[25] Rana, K., Biswas, P. and Salam, M. (2020) Evaluation of Jute Leaf as Substitute of Fish Meal in the Diet of Mrigal (*Cirrhinus cirrhosus*) Fingerlings. *International Journal of Agricultural Research*, *Innovation and Technology*, **10**, 117-122. https://doi.org/10.3329/ijarit.v10i1.48103

[26] Liu, Z., Zeng, X.-A. and Ngadi, M. (2018) Enhanced Extraction of Phenolic Compounds from Onion by Pulsed Electric Field (PEF). *Journal of Food Processing and Preservation*, **42**, e13755. https://doi.org/10.1111/jfpp.13755

[27] Prakash, B., Ed. (2020) Functional and Preservative Properties of Phytochemicals. Academic Press.

[28] Genkinger, J.M., Platz, E.A., Hoffman, S.C., Comstock, G.W. and Helzlsouer, K.J. (2004) Fruit, Vegetable, and Antioxidant Intake and All-Cause, Cancer, and Cardiovascular Disease Mortality in a Community-Dwelling Population in Washington County, Maryland. *American Journal of Epidemiology*, **160**, 1223-1233. https://doi.org/10.1093/aje/kwh339

[29] Afolayan, A.J. and Jimoh, F.O. (2009) Nutritional Quality of Some Wild Leafy Vegetables in South Africa. *International Journal of Food Sciences and Nutrition*, **60**, 424-431. https://doi.org/10.1080/09637480701777928

[30] Ramakrishina, A. and Ravishankar G. (2011). Influence of Abiotic Stress Signals on Secondary Metabolites in Plants. *Plants Signaling and Behavior*, **6**, 1720-1731.

[31] Chen, S.-L., Yu, H., Luo, H.-M., Wu, Q., Li, C.-F. and Steinmetz, A. (2016) Conservation and Sustainable Use of Medicinal Plants: Problems, Progress, and Prospects. *Chinese Medicine*, **11**, Article No. 37. https://doi.org/10.1186/s13020-016-0108-7

[32] Tesfay, S., Shimelis, H., Mwandzingeni, L. and Tsilo, T.J. (2016) Screening of Bread

Wheat Genotypes for Drought Tolerance Using Phenotypic and Proline Analysis. *Frontiers in Plant Science*, **7**, Article 1276.https://doi.org/10.3389/fpls.2016.01276

[33] Giro, A. and Ferrante, A. (2016) Yield and Quality of *Corchorus olitorius* Baby Leaf Grown in a Floating System. *The Journal of Horticultural Science and Biotechnology*, **91**, 603-610. https://doi.org/10.1080/14620316.2016.1200955

[34] Al Batran, R., Al-Bayaty, F., Ameen Abdulla, M., Jamil Al-Obaidi, M.M., Hajrezaei, M., Hassandarvish, P., *et al*. (2013) Retracted: Gastroprotective Effects of *Corchorus olitorius* Leaf Extract against Ethanol-Induced Gastric Mucosal Hemorrhagic Lesions in Rats. *Journal of Gastroenterology and Hepatology*, **28**, 1321-1329. https://doi.org/10.1111/jgh.12229

[35] Ashafa, A.O.T., Abass, A.A., Osinaike, T. and Lewu, F.B. (2013) Morphological Characters and Ascorbic Acid Content of an Elite Genotype of*Corchorus olitorius*: The Influence of Moisture Stress. *South African Journal of Plant and Soil*, **30**, 113-117. https://doi.org/10.1080/02571862.2013.811300

[36] Ewetola, E.A. and Fasanmi, T.F. (2015) Growth Responses of Okra (*Albemoschusesculentus*) and Jute Mallow (*Corchorusoitorius*) to Water Stress and Non-Water Stress Conditions. *International Letters of Chemistry*, *Physics and Astronomy*, **59**, 10-16. https://doi.org/10.56431/p-zfm822

[37] Ben Yakoub, A.R., Abdehedi, O., Jridi, M., Elfalleh, W., Nasri, M. and Ferchichi, A. (2018) Flavonoids, Phenols, Antioxidant, and Antimicrobial Activities in Various Extracts from Tossa Jute Leave (*Corchorus olitorus* L.). *Industrial Crops and Products*, **118**, 206-213. https://doi.org/10.1016/j.indcrop.2018.03.047

[38] Biswas, A., Dey, S., Li, D., Liu, Y., Zhang, J., Huang, S., *et al*. (2020) Comparison of Phytochemical Profile, Mineral Content, and *in Vitro* Antioxidant Activities of *Corchorus capsularis* and *Corchorus olitorius* Leaf Extracts from Different Populations. *Journal of Food Quality*, **2020**, Article ID: 2931097. https://doi.org/10.1155/2020/2931097

[39] Krishna, H. and Parashar, A. (2012) Phytochemical Constituents and Antioxidant Activities of Some Indian Jujube (*Ziziphus mauritiana* Lamk.) Cultivars. *Journal of Food Biochemistry*, **37**, 571-577. https://doi.org/10.1111/jfbc.12008

[40] Neffati, N., Aloui, Z., Karoui, H., Guizani, I., Boussaid, M. and Zaouali, Y. (2017) Phytochemical Composition and Antioxidant Activity of Medicinal Plants Collected from the Tunisian Flora. *Natural Product Research*, **31**, 1583-1588. https://doi.org/10.1080/14786419.2017.1280490

[41] Panche, A.N., Diwan, A.D. and Chandra, S.R. (2016) Flavonoids: An Overview. *Journal of Nutritional Science*, **5**, e47. https://doi.org/10.1017/jns.2016.41

[42] Nithiya, T., Alphonse, J. and Ligoriya, M. (2015) Effects of Organic and Inorganic Fertilizers on Growth, Phenolic Compounds and Antioxidant Activity of *Solanum nigrum* L. *World Journal of Pharmacy and Phaceutical Sciences*, **4**, 808-822.

[43] Sereme, A., Dabire, C., Koala, M., Somda, M.K. and Traore, A.S. (2016) Influence of Organic and Mineral Fertilizers on the Antioxidants and Total Phenolic Compounds Level in Tomato (*Solanum lycopersicum*) var. Mongal F1. *Journal of Experimental Biology and Agricultural Sciences*, **4**, 414-420. https://doi.org/10.18006/2016.4(4).414.420

[44] Sadat, A., Hore, M., Chakraborty, K. and Roy, S. (2017) Phytochemical Analysis and Antioxidant Activity of Methanolic Extract of Leaves of *Corchorus olitorius*. *International Journal of Current Pharmaceutical Research*, **9**, 59-63. https://doi.org/10.22159/ijcpr.2017v9i5.22138

[45] Raaman, N. (2015) Antioxidant Activities and Phytochemical Analysis of Methanol

Extract of Leaves of *Hygrophila auriculata* (Schumach) Heine. *International Journal of Current Pharmaceutical Research*, **7**, 100-105.

[46] Chigurupati, S., Aladhadh, H.S., Alhowail, A., Selvarajan, K.K. and Bhatia, S. (2020) Phytochemical Composition, Antioxidant and Antidiabetic Potential of Methanolic Extract from *Corchorus olitorius* Linn. Grown in Saudi Arabia. *Medicinal Plants-International Journal of Phytomedicines and Related Industries*, **12**, 71-76. https://doi.org/10.5958/0975-6892.2020.00010.6

[47] Azuma, K., Nakayama, M., Koshioka, M., Ippoushi, K., Yamaguchi, Y., Kohata, K., *et al*. (1999) Phenolic Antioxidants from the Leaves of *Corchorus olitorius* L. *Journal of Agricultural and Food Chemistry*, **47**, 3963-3966. https://doi.org/10.1021/jf990347p

[48] Oboh, G., Raddatz, H. and Henle, T. (2009) Characterization of the Antioxidant Properties of Hydrophilic and Lipophilic Extracts of Jute (*Corchorus olitorius*) Leaf. *International Journal of Food Sciences and Nutrition*, **60**, 124-134. https://doi.org/10.1080/09637480902824131

[49] Kuete, V. (2017) Medicinal Spices and Vegetables from Africa. Academic Press, 497-512.

[50] Innami, S., Ishida, H., Nakamura, K., Kondo, M., Tabata, K., Koguchi, T., *et al*. (2005) Jew's Mellow Leaves (*Corchorus olitorius*) Suppress Elevation of Postprandial Blood Glucose Levels in Rats and Humans. *International Journal for Vitamin and Nutrition Research*, **75**, 39-46. https://doi.org/10.1024/0300-9831.75.1.39

[51] Ibrahim, M.H., Jaafar, H.Z.E., Karimi, E. and Ghasemzadeh, A. (2013) Impact of Organic and Inorganic Fertilizer Application on Phytochemicals and Antioxidant Activity of Kacip Fartima (*Labisia pumila* Benth).*Molecules*, **18**, 10973-10988. https://doi.org/10.3390/molecules180910973

[52] Tarozzi, A., Hrelia, S., Angeloni, C., Morroni, F., Biagi, P., Guardigli, M., Cantelli-Forti, G. and Hrelia, P. (2006) Antioxidant Effectiveness of Organically and Non-Organically Grown Red Oranges in Cell Culture Systems. *European Journal of Nutrition*, **45**, 152-158.https://doi.org/10.1007/s00394-005-0575-6

[53] Parr, A.J. and Bolwell, G.P. (2000) Phenols in the Plant and in Man. The Potential for Possible Nutritional Enhancement of the Diet by Modifying the Phenols Content and Profile. *Journal of the Science of Food and Agriculture*, **80**, 985-1012. https://doi.org/10.1002/(SICI)1097-0010(20000515)80:7<985::AID-JSFA572>3.3.CO;2-Z

[54] Barker, A.V. and Mills, H.A. (1980) Ammonium and Nitrate Nutrition of Horticultural Crops. In: Janick, J., Ed., *Horticultural Reviews*, Vol. 2, John Wiley & Sons Ltd., 395-423.https://doi.org/10.1002/9781118060759.ch8

[55] Chen, Y., Gup, Q., Liu, L., Liao, L. and Zhu, Z. (2011) Influence of Fertilization and Drought Stress on the Growth and Production of Secondary Metabolites in *Prunella vulgaris* L. *Journal of Medical Plant Research*, **5**, 1749-1755.

[56] Yadav, B., Jogawat, A., Rahman, M.S. and Narayan, O.P. (2021) Secondary Metabolites in the Drought Stress Tolerance of Crop Plants: A Review. *Gene Reports*, **23**, Article 101040. https://doi.org/10.1016/j.genrep.2021.101040

[57] Shao, H.-B., Chu, L.-Y., Jaleel, C.A. and Zhao, C.-X. (2008) Water-Deficit Stress-Induced Anatomical Changes in Higher Plants. *Comptes Rendus. Biologies*, **331**, 215-225. https://doi.org/10.1016/j.crvi.2008.01.002

[58] Akula, R. and Ravishankar, G.A. (2011) Influence of Abiotic Stress Signals on Secondary Metabolites in Plants. *Plant Signaling & Behavior*, **6**, 1720-1731. https://doi.org/10.4161/psb.6.11.17613

[59] Gharibi, S., Tabatabaei, B.E.S., Saeidi, G. and Goli, S.A.H. (2015) Effect of Drought Stress on Total Phenolic, Lipid Peroxidation, and Antioxidant Activity of *Achillea* Species. *Applied Biochemistry and Biotechnology*, **178**, 796-809. https://doi.org/10.1007/s12010-015-1909-3

[60] Oh, M.-M., Carey, E.E. and Rajashekar, C.B. (2010) Regulated Water Deficits Improve Phytochemical Concentration in Lettuce. *Journal of the American Society for Horticultural Science*, **135**, 223-229. https://doi.org/10.21273/jashs.135.3.223

[61] Rahman, K., Rahman, M., Ahmed, N., Alam, M.M., Rahman, A., Islam, M.M., *et al*. (2021) Morphophysiological Changes and Reactive Oxygen Species Metabolism in *Corchorus olitorius* L. under Different Abiotic Stresses. *Open Agriculture*, **6**, 549-562. https://doi.org/10.1515/opag-2021-0040

[62] Quin, M.B., Flynn, C.M. and Schmidt-Dannert, C. (2014) Traversing the Fungal Terpenome. *Natural Product Reports*, **31**, 1449-1473. https://doi.org/10.1039/c4np00075g

[63] Suguiyama, V.F., Rodriguez, J.D.P., Dos Santos, T.C.N., Lira, B.S., *et al*. (2022) Regulatory Mechanism behind the Phenotypic Plasticity Associated with *Setaria italica* Water Deficit Tolerance. *Plant Molecular Biology*, **109**, 761-780. https://doi.org/10.1007/s11103-022-01273-w

[64] Deluc, L.G., Quilici, D.R., Decendit, A., Grimplet, J., Wheatley, M.D., Schlauch, K.A., *et al*. (2009) Water Deficit Alters Differentially Metabolic Pathways Affecting Important Flavor and Quality Traits in Grape Berries of Cabernet Sauvignon and Chardonnay. *BMC Genomics*, **10**, Article No. 212. https://doi.org/10.1186/1471-2164-10-212

[65] Dhar, P., Ojha, D., Kar, C.S. and Mitra, J. (2018) Differential Response of Tossa Jute (*Corchorus olitorius*) Submitted to Water Deficit Stress. *Industrial Crops and Products*, **112**, 141-150. https://doi.org/10.1016/j.indcrop.2017.10.044

[66] Nakabayashi, R., Yonekura-Sakakibara, K., Urano, K., Suzuki, M., Yamada, Y., Nishizawa, T., (2014) Enhancement of Oxidative and Drought Tolerance in Arabidopsis by over Accumulation of Antioxidant Flavonoids. *The Plant Journal*, **77**, 367-379. https://doi.org/10.1111/tpj.12388

[67] Shojaie, B., Mostajeran, A. and Ghannadian, M. (2016) Flavonoid Dynamic Responses to Different Drought Conditions: Amount, Type, and Localization of Flavonols in Roots and Shoots of *Arabidopsis thaliana* L. *Turkish Journal of Biology*, **40**, 612-622. https://doi.org/10.3906/biy-1505-2

[68] Wang, W., Xin, H., Wang, M., Ma, Q., Wang, L., Kaleri, N.A., *et al*. (2016) Transcriptomic Analysis Reveals the Molecular Mechanisms of Drought-Stress-Induced Decreases in *Camellia sinensis* Leaf Quality. *Frontiers in Plant Science*, **7**, Article 385. https://doi.org/10.3389/fpls.2016.00385

[69] Guzzetti, L., Panzeri, D., Ulaszewska, M., Sacco, G., Forcella, M., Fusi, P., *et al*. (2021) Assessment of Dietary Bioactive Phenolic Compounds and Agricultural Sustainability of an African Leafy Vegetable *Corchorus olitorius* L. *Frontiers in Nutrition*, **8**, Article 667812. https://doi.org/10.3389/fnut.2021.667812

[70] Sarker, U. and Oba, S. (2018) Drought Stress Enhances Nutritional and Bioactive Compounds, Phenolic Acids and Antioxidant Capacity of *Amaranthus* Leafy Vegetable. *BMC Plant Biology*, **18**, Article No. 258. https://doi.org/10.1186/s12870-018-1484-1

[71] Saad-Allah, K.M. and Nessem, A.A. (2020) Parsley Extract Improves Physio-Biochemical Traits and the Activity of the Defense System in Mallow (*Corchorus olitorius* L.) under Na_2SO_4 Salinity. *Gesunde Pflanzen*, **72**, 321-334.

https://doi.org/10.1007/s10343-020-00515-5

[72] Ma, H., Yang, R., Wang, Z., Yu, T., Jia, Y., Gu, H., Wang, X. and Ma, H. (2011) Screening of Salinity Tolerant Jute (*Corchorus capsularis* and *olitorius*) Genotypes via Phenotypic and Physiology-Assisted Procedures. *Pakistan Journal of Botany*, **43**, 2655-2660.

[73] Roy Chowdhury, S. and Choudhuri, M.A. (1986) Effects of Calcium Ions on Responses of Two Jute Species under Water-Deficit Stress. *Physiologia Plantarum*, **68**, 86-92. https://doi.org/10.1111/j.1399-3054.1986.tb06600.x

[74] Saleem, M.H., Ahmad, S., Urooj, S., Rehaman, M., Liu, L. and Saeed, F. (2019) Screening of Different Varieties of Jute Seedling under Copper Stress. *Annals of Agricultural & Crop Sciences*, **4**, 1043.

[75] Okello, O.P., Gweyi, J.P.O., Nawiri, M.P. and Musila, W. (2017) Effects of Water Stress on Phenolic Content and Antioxidant Activity of African Nightshades. *Biofarmasi Journal of Natural Product Biochemistry*, **15**, 79-95. https://doi.org/10.13057/biofar/f150204

[76] Förster, N., Dilling, S., Ulrichs, C. and Huyskens-Keil, S.H. (2023) Nutritional Diversity in Leaves of Various Amaranth (*Amaranthus* spp.) Genotypes and Its Resilience to Drought Stress. *Journal of Applied Botany and Food Quality*, **96**, 1-10.

[77] Eichholz, I., Förster, N., Ulrichs, C., Schreiner, M. and Huyskens-Keil, S. (2014) Survey of Bioactive Metabolites in Selected Cultivars and Varieties of *Lactuca sativa* L. under Water Stress. *Journal of Applied Botany and Food Quality*, **87**, 265-273.

[78] Mechri, B., Tekaya, M., Hammami, M. and Chehab, H. (2020) Effects of Drought Stress on Phenolic Accumulation in Greenhouse-Grown Olive Trees (*Olea europaea*). *Biochemical Systematics and Ecology*, **92**, Article 104112. https://doi.org/10.1016/j.bse.2020.104112

[79] Cetinkaya, H., Koc, M. and Kulak, M. (2016) Monitoring of Mineral and Polyphenol Content in Olive Leaves under Drought Conditions: Application Chemometric Techniques. *Industrial Crops and Products*, **88**, 78-84. https://doi.org/10.1016/j.indcrop.2016.01.005

[80] Petridis, A., Therios, I., Samouris, G., Koundouras, S. and Giannakoula, A. (2012) Effect of Water Deficit on Leaf Phenolic Composition, Gas Exchange, Oxidative Damage and Antioxidant Activity of Four Greek Olive (*Olea europaea* L.) Cultivars. *Plant Physiology and Biochemistry*, **60**, 1-11. https://doi.org/10.1016/j.plaphy.2012.07.014

[81] Sakonjic, A., Matijevic, A., Hamidovic, S., Cengk, L. and Gavric, T. (2023) Effects of Mulching and Irrigation on Antioxidant Activity and Antimicrobial Properties of Basil (*Ocimum basilicum* L). *Conference Paper*, Springer Link, 47-55.

[82] Farooq, M., Basra, S.M.A., Wahid, A., Cheema, Z.A., Cheema, M.A. and Khaliq, A. (2008) Physiological Role of Exogenously Applied Glycinebetaine to Improve Drought Tolerance in Fine Grain Aromatic Rice (*Oryzasativa* L.). *Journal of Agronomy and Crop Science*, **194**, 325-333. https://doi.org/10.1111/j.1439-037x.2008.00323.x

[83] Rady, M.M., Belal, H.E.E., Gadallah, F.M. and Semida, W.M. (2020) Selenium Application in Two Methods Promotes Drought Tolerance in *Solanum lycopersicum* Plant by Inducing the Antioxidant Defense System. *Scientia Horticulturae*, **266**, Article 109290. https://doi.org/10.1016/j.scienta.2020.109290

[84] Abdelhamid, M.T., Selim, E.M. and EL-Ghamry, A.M. (2010) Integrated Effects of Bio and Mineral Fertilizers and Humic Substances on Growth, Yield and Nutrient Contents of Fertigated Cowpea (*Vigna unguiculata* L.) Grown on Sandy Soils.

Journal of Agronomy, **10**, 34-39. https://doi.org/10.3923/ja.2011.34.39

[85] Kate, S., Tovihoudji, P.G., Batamoussi-Hermann, M., Sossa, L.E., Idohou, R., Agbangba, E.C. and Sinsin, B. (2020). Growth, Yield and Nutrients Use Efficiency of *Corchorus olitorius* under Irrigated and Rain-Fed Conditions in Northeastern Benin (West Africa). *Asian Journal of Agricultural and Horticultural Research*, **5**, 32-44. https://doi.org/10.9734/ajahr/2020/v5i330054

[86] Caretto, S., Linsalata, V., Colella, G., Mita, G. and Lattanzio, V. (2015) Carbon Fluxes between Primary Metabolism and Phenolic Pathway in Plant Tissues under Stress. *International Journal of Molecular Sciences*, **16**, 26378-26394. https://doi.org/10.3390/ijms161125967

[87] Li, J., Zhu, Z. and Gerendás, J. (2008) Effects of Nitrogen and Sulfur on Total Phenolics and Antioxidant Activity in Two Genotypes of Leaf Mustard. *Journal of Plant Nutrition*, **31**, 1642-1655. https://doi.org/10.1080/01904160802244860

[88] Glynn, C., Herms, D.A., Orians, C.M., Hansen, R.C. and Larsson, S. (2007) Testing the Growth-Differentiation Balance Hypothesis: Dynamic Responses of Willows to Nutrient Availability. *New Phytologist*, **176**, 623-634. https://doi.org/10.1111/j.1469-8137.2007.02203.x

[89] Glymn, C., Herms, D., Orians, C., Hansen, R. and Larson, S. (2008) Testing the Growth and Differentiation Balance Hypothesis: Dynamic Responses of Willow to Nutrient Availability. *New Phytology*, **176**, 623-634.

[90] Zhao, C., Wang, Z., Cui, R., Su, L., Sun, X., Borras-Hidalgo, O., *et al*. (2021) Effects of Nitrogen Application on Phytochemical Component Levels and Anticancer and Antioxidant Activities of *Allium fistulosum*. *PeerJ*, **9**, e11706. https://doi.org/10.7717/peerj.11706

[91] Dong, F., Hu, J., Shi, Y., Liu, M., Zhang, Q. and Ruan, J. (2019) Effects of Nitrogen Supply on Flavonol Glycoside Biosynthesis and Accumulation in Tea Leaves (*Camellia sinensis*). *Plant Physiology and Biochemistry*, **138**, 48-57. https://doi.org/10.1016/j.plaphy.2019.02.017

[92] Mogren, L.M., Olsson, M.E. and Gertsson, U.E. (2006) Quercetin Content in Field-Cured Onions (*Allium cepa* L.): Effects of Cultivar, Lifting Time, and Nitrogen Fertilizer Level. *Journal of Agricultural and Food Chemistry*, **54**, 6185-6191. https://doi.org/10.1021/jf060980s

[93] Allahdadi, M. and Farzane, P. (2018) Influence of Different Levels of Nitrogen Fertilizers on Some Phytochemical Characteristics of Artichoke Leaves. *Journal of Medicinal Plants*, **6**, 109-115.

[94] Ibrahim, M.H., Jaafar, H.Z.E., Rahmat, A. and Rahman, Z.A. (2011) Effects of Nitrogen Fertilization on Synthesis of Primary and Secondary Metabolites in Three Varieties of Kacip Fatimah (*Labisia pumila* Blume). *International Journal of Molecular Sciences*, **12**, 5238-5254. https://doi.org/10.3390/ijms12085238

[95] Allegro, G., Pastore, C., Valentini, G., Muzzi, E. and Filippetti, I. (2016) Influence of Berry Ripeness on Accumulation, Composition and Extractability of Skin and Seed Flavonoids in cv. Sangiovese (*Vitis vinifera* L.). *Journal of the Science of Food and Agriculture*, **96**, 4553-4559. https://doi.org/10.1002/jsfa.7672

[96] Liu, D., Liu, W., Zhu, D., Geng, M., Zhou, W. and Yang, T. (2010) Nitrogen Effects on Total Flavonoids, Chlorogenic Acid, and Antioxidant Activity of the Medicinal Plant *Chrysanthemum morifolium*. *Journal of Plant Nutrition and Soil Science*, **173**, 268-274. https://doi.org/10.1002/jpln.200900229

[97] Arista, R.A., Priosoeryanto, B.P. and Nurcholis, W. (2023) Total Phenolic, Flavonoids Contents, and Antioxidant Activities in the Stems and Rhizomes of Java Car-

damom as Affected by Shading and N Fertilizer Dosages. *Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi*, **33**, 29-39. https://doi.org/10.29133/yyutbd.1193221

[98] Tarfaoui, K., Brhadda, N., Ziri, R., Oubihi, A., Imtara, H., Haida, S., *et al*. (2022) Chemical Profile, Antibacterial and Antioxidant Potential of *Zingiber officinale* Roscoe and *Elettaria cardamomum* (L.) Maton Essential Oils and Extracts. *Plants*, **11**, Article 1487. https://doi.org/10.3390/plants11111487

[99] Carol, M.M., Joshua, O.O. and Robert, M.G. (2021) Effect of NPK Fertilizer Rates on Secondary Metabolites of Pepino Melon (*Solanum muricatum* Aiton). *Journal of Horticulture and Forestry*, **13**, 25-34. https://doi.org/10.5897/jhf2020.0657

[100] Munene, R., Changamu, E., Korir, N. and Joseph, G. (2017) Effects of Different Nitrogen Forms on Growth, Phenolics, Flavonoids and Antioxidant Activity in Amaranth Species. *Tropical Plant Research*, **4**, 81-89. https://doi.org/10.22271/tpr.2017.v4.i1.012

[101] Borgognone, D., Colla, G., Rouphael, Y., Cardarelli, M., Rea, E. and Schwarz, D. (2013) Effect of Nitrogen Form and Nutrient Solution pH on Growth and Mineral Composition of Self-Grafted and Grafted Tomatoes. *Scientia Horticulturae*, **149**, 61-69. https://doi.org/10.1016/j.scienta.2012.02.012

[102] Vanitha, T. and Mehalai, V. (2016) Studies on Quality Changes of Pepino (*Solanum muricatum*) Fruit during Storage. *International Journal of Science and Technology*, **4**, 138-143.

[103] Peng, L.-C. and Ng, L.-T. (2022) Impacts of Nitrogen and Phosphorus Fertilization on Biomass, Polyphenol Contents, and Essential Oil Yield and Composition of *Vitex negundo* Linn. *Agriculture*, **12**, Article 859. https://doi.org/10.3390/agriculture12060859

[104] De Long, J.R., Sundqvist, M.K., Gundale, M.J., Giesler, R. and Wardle, D.A. (2015) Effects of Elevation and Nitrogen and Phosphorus Fertilization on Plant Defence Compounds in Subarctic Tundra Heath Vegetation. *Functional Ecology*, **30**, 314-325. https://doi.org/10.1111/1365-2435.12493

[105] Ogembo, J.O. (2015) Effects of Phosphorus Deficiency on Secondary Metabolites and Distribution of African Nightshade in Siafy and Kiisi Counties, Kenya. Master's Thesis, Kennyatta University.

[106] Olesińska, K., Sugier, D. and Kaczmarski, Z. (2021) Yield and Chemical Composition of Raw Material from Meadow Arnica (*Arnica chamissonis* Less.) Depending on Soil Conditions and Nitrogen Fertilization. *Agriculture*, **11**, Article 810. https://doi.org/10.3390/agriculture11090810

[107] Larbat, R., Olsen, K.M., Slimestad, R., Løvdal, T., Bénard, C., Verheul, M., *et al*. (2012) Influence of Repeated Short-Term Nitrogen Limitations on Leaf Phenolics Metabolism in Tomato. *Phytochemistry*, **77**, 119-128. https://doi.org/10.1016/j.phytochem.2012.02.004