Research
Journal of
Botany

OPEN ACCESS

Impact of Environmental Changes on the Chemical Composition of Mosquitocidal Plants

Kayode David Ileke and Naheemot Atinuke Babatunde
Department of Biology, School Life of Sciences, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria

ABSTRACT
Mosquitocidal plants known for their ability to kill and repel mosquitoes depend on their chemical composition to be effective. However, the production and abundance of these chemical compounds are increasingly threatened by major environmental changes. Warmer temperatures, increased UV-B radiation, elevated CO_2 levels and altered precipitation patterns are major factors that can influence the balance of these phytochemicals. In addition, pollution and other anthropogenic activities such as dust pollution can cause physiological stress for plants and consequently affect phytochemicals production. These changes have a huge impact on the use of traditional remedies available to locals, reliance on chemical insecticides, disease transmission, and environmental degradation among others. Addressing these issues requires a multifaceted approach involving research, adaptation strategies, community involvement, and sustainable cultivation practices. This review highlights the importance of understanding how environmental factors are affecting mosquitocidal plants and stresses the need for adaptive strategies to ensure their continued efficacy. Conclusively, preserving the efficacy of mosquitocidal plants necessitates an integrative effort involving scientific advancements and community-based initiatives to combat the dynamic challenges posed by environmental changes.

KEYWORDS
Mosquitocidal plants, environmental changes, chemical composition, malaria

INTRODUCTION

Mosquitoes are without a doubt the vectors of disease that are arthropods and are of significant public health importance. The endemicity of diseases like malaria, lymphatic filariasis, and a variety of viral infections in a region is dependent on the presence of vectors that can transmit these diseases. *Plasmodium falciparum* and *Plasmodium vivax* which affect nearly 500 million people each year and kill nearly 3 million people cause malaria in human beings[1]. Several people have been infected with mosquito-borne arboviruses, with the most common being yellow fever and dengue fever[2]. In 2019, there were 229 million reported cases of malaria globally, resulting in 409,000 deaths. The African regional disease accounts for 90% of all cases and deaths each year[3].

The reduction in the transmission of deadly diseases like malaria, dengue fever, and the Zika virus is largely dependent on the control of mosquitoes. Mosquito control with insecticides is now the most widely used disease control strategy. Insecticide resistance has emerged, and synthetic insecticides have

ISSN: 2152-0461 (Online)
ISSN: 1816-4919 (Print)
https://doi.org/10.3923/rjb.2025.88.102

Received: 07 Dec. 2024
Accepted: 28 Jan. 2025
Published: 29 Jan. 2025

been discovered to be harmful to the environment, non-target species, and human health. Bio-control strategies for mosquito vectors based on plant-based materials are encouraged to avoid these issues. For centuries, humans have used plant materials by bruising or burning them, which causes the phytochemicals secretion from the plants that help to ward off biting insects particularly mosquitoes[4]. These plants secrete very volatile compounds that repel the hematophagous insects away from the hosts[5]. Secondary compounds from plants, such as alkanes, alkenes, alkynes, simple aromatics, lactones, essential oils, fatty acids, terpenes, alkaloids, steroids, flavonoids, and pterocarpus, have shown potential in controlling mosquito larvae. Saponin in *M. koenigii* causes death to adult insects by reducing the insect's ability to uptake food, which consequently leads to instability while hindering development and reproduction[6]. Flavonoids are important in using plants for insect control because they have been found to attract insects to toxic plants or repel insects. They have also been found to suppress egg-laying in insects. The geographical distribution and the chemical composition of the world's vegetation, especially plants that are used for medicine in most of the world is changing rapidly. Temperature and wind pattern changes affect rainfall which then affects the development and growth of plants. Research has identified the presence of different secondary metabolites in medicinal and aromatic plants. Due to growing limitations on the use of synthetic insecticides, there is greater attention on sustainable methods of controlling hematophagous insects, such as the use of plants. Environment and agronomic practices both influence phytochemical content in plants[7]. Therefore, a thorough understanding of the impacts of the environmental and agronomic factors is required to improve the level of predictability of desired compounds, whether for human health or pest control. The objective of this study is to investigate the effect of environmental changes on the chemical composition of mosquitocidal plants. The study aims to identify how these changes influence the plant's effectiveness in mosquito control.

Chemical composition of mosquitocidal plants: Plants are composed of secondary metabolites which they use as a way to protect themselves from the herbivores who feed on them and other abiotic pressures. Several categories of phytochemicals, primarily secondary metabolites derived from various plant species-including alkaloids, steroids, terpenoids, essential oils, and phenolics have been documented for their insecticidal properties. More than 2,000 plant species have been recognized for producing chemical compounds and metabolites that are valuable in pest management strategies. Members of the plant families *Solanaceae*, *Asteraceae*, *Cladophoraceae*, *Labiatae*, *Miliaceae*, *Oocystaceae*, and *Rutaceae* have varying degrees of larval, adulticidal or repellent activity against various mosquito species[8].

Phytochemicals in essential oil: Essential oils have proven to be effective in combating various pests and safeguarding crops globally, offering a promising alternative to synthetic insecticides for mosquito control. These oils consist of several volatile compounds, such as hydrocarbons (terpenes and sesquiterpenes), oxygenated hydrocarbons, and phenylpropenes. High larvicidal and pupicidal activities have been reported for plant oils gotten from *Cinnamomum verum*, *Cuminum cyminum*, *Syzygium aromaticum*, *Laurus nobilis*, *Citrus aurantifolia*, *Lippia berlandieri*, and *Pimpinella anisum* against *Cx. quinquefasciatus*[9]. Essential oils extracted from *Tagetes lucida*, *Lippia alba*, *Lippia origanoides*, *Eucalyptus citriodora*, *Cymbopogon citratus*, *Cymbopogon flexuosus*, *Citrus sinensis*, *Swinglea glutinosa*, and *Cananga odorata* have shown mortality against *Ae. aegypti* larvae[10]. Additionally, oils like peppermint, basil, rosemary, and citronella from *Mentha piperita*, *Ocimum basilicum*, *Rosmarinus officinalis*, *Cymbopogon nardus*, and *Apium graveolens* suppress fecundity and demonstrate effectiveness against the development of eggs into larvae in *Aedes aegypti*[11]. *Cymbopogon proximus*, *Ocimum canum* and *Lippia multiflora* plant oils have shown effective mortality activity against the larvae and eggs of *An. gambiae* and *Ae. aegypti* mosquitoes[12]. Furthermore, oils from *Cinnamomum osmophloeum* and *Carum copticum* demonstrated mortality against *Cx. quinquefasciatus* and *Cx. Pipiens* larvae[13]. Essential oils disrupt the insect nervous system, inducing neurotoxicity through multiple mechanisms, such as inhibiting acetylcholinesterase (AChE) activity, blocking octopamine receptors, and interfering with GABA-gated chloride channels[14]. Monoterpenes which is the functional compound responsible for AChE interference in insects is the main composition of about 90% of essential oils and generally potential plant-based larvicides[15]. The Thymus plant produces Monoterpenes which have been proven to be effective in deterring Culex mosquitoes and have shown significant mortality activity against larvae of Culex mosquitoes including *Pipiens, Pallens* and *Quinquefasciatus*[16]. Mortality activities of β-citronellol, geraniol and linalool which are compounds from *Pelargonium roseum* essential oil were also observed against *Cx. Pipiens*[17]. The composition of an essential oil obtained from the flowers of *Cannabis sativa* L., with significant mortality activity against mosquito larvae and adults was found to be 25.0% myrcene, 45.4% beta-caryophyllene,17.9% α-pinene, 8.3% humulene, 5.2% β-pinene, 5.1% ocimene, and 3.0% of farnesene[18].

Terpenes: This compound is plentiful in citrus, eucalyptus and conifers which are found in their leaves, flowers, stems, and roots. Terpenes contain over 25,000 volatile organic compounds of different concentrations and levels of toxicity that are useful for insect and pathogenic microbe defense. Cyclopentanoid (iridoid), a compound derived from monoterpene, is extremely bitter and an effective insect repellent. Iridoids can inhibit the production of prostaglandins, thereby suppressing insect growth and development. Iridoid increases the larval stage of insects thereby reducing insect growth and survival rates *in vitro*[19]. Pyrethroids are neurotoxin-modulating monoterpene esters elicited by flowers and leaves. Because studies have shown that pyrethroid is environmentally safe, it is used as an active ingredient in the majority of commercial insecticides. Mosquito repellents include terpene-rich *Chenopodium ambrosioides* and neem extracts. Callicarpenal, a naturally occurring type of terpenoid from *Callicarpa Americana* has been studied for its significant repellent activities against biting from mosquitoes[20].

Alkaloids: Alkaloids are naturally occurring nitrogen-containing compounds which are frequently synthesized in plants. This compound from these plants' alkaloids is widely used in conventional insect repellents[21,22]. Unlike essential oils, alkaloids are non-volatile; however, they prove effective as mosquito repellents when plants are burned to release smoke, which deters insects[23]. Ricinine is found in castor bean extracts (*Ricinus communis*) which have a strong insecticidal effect. High mortality rates were recorded for its activity against *Anopheles arabiensis* larvae[24]. Furthermore, *Ricinus communis* produces pyridine alkaloids which showed larvicidal and adulticidal activity against *An. gambiae*[25]. *Aedes albopictus*, *Culex pipiens pallens*, and *Aedes aegypti* have also demonstrated susceptibility to the larvicidal activity of alkaloids[26]. Alkaloids derived from the *Arachis hypogaea* plant have also been shown to cause mortality against *Anopheles stephensi* and *Aedes aegypti* mosquito larvae[27]. Additionally, *Nicotiana tobacco* produces Nicotine, which is an alkaloid. Nicotine is mostly made up of phenols that mimic neurotransmitters that cause symptoms resembling those caused by organophosphate or carbamate insecticides, same with nornicotine, and anabasine[28].

Steroids: They fulfill diverse tasks such as hormones, pheromones or insect deterrents. A previous study has isolated a steroid compound from the foliage of *Cestrum diurnum* effective against *An. subpictus*[29]. Similarly, the activity of the methanol extract of mature foliage of *Solanum villosum* has been reported against *Culex quinquefasciatus* fourth instar larvae[30]. Also, β-sitosterol a new phytosteroid isolated from *Abutilon indicum*, has been reported for its mortality activity against *Aedes*, *Anopheles* and *Culex* mosquito larvae[31]. Banerjee *et al.*[32] observed the presence of steroidal compounds in the methanol extracts of *Limonia acidissima* leaves which showed significant larvicidal activity with LC_{50} values of 1.73 ppm against *Culex* mosquitoes after exposure for three days.

FACTORS THAT DETERMINE THE PRODUCTION OF PHYTOCHEMICALS

Natural insect management agents are increasingly being used to manage different arthropod pests and vectors because they provide a safer alternative to hazardous chemical insecticides. A holistic understanding of soil biological and ecological factors can improve efficacy and bio-control success. Factors such as the variety of the cultivar, the specific plant species, the age of the plant, the particular organ being examined, as well as environmental conditions like weather and soil type, along with cultivation techniques and agricultural practices, all contribute to the variability of phytochemical levels and profiles in plants, such as alkaloids[33]. Environmental conditions such as drought, sulfate and nitrogen nutrients, season, and the diurnal cycle have a significant impact on these phytochemicals and their associated enzymes[7]. Overall, the level of phytochemical production is influenced by the interplay between environmental and genetic factors.

Formation of the plant organ: The developmental stage of the organ of a plant can influence the phytochemical composition of that plant[34]. The phytochemical composition of a plant organ can change substantially, with about 10% traces of the phytochemicals in the early stages to approximately 50-70% phytochemical content when the plant flowers, while in some cases, the phytochemicals accumulate in abundant before the full development of the organ. A decrease in the amount of eugenol and methyl eugenol was observed as the leaves of *Ocimum sanctum* begin to develop. It is also worthy noting that yield and composition variability with organ formation might be due to the secretion structure. Plants with their secretory structures outside the plants may release secretions with organ maturation as a result of trichome cuticle disruption. In contrast, those with their secretions internally typically demonstrate consistency in the composition of their phytochemicals and their yield[35].

Plant part: Differences in composition can also be seen in flowers that are adapted to be pollinated by insects (entomophilous flowers), where secretion of phytochemicals can serve as orientation cues, and as such phytochemicals released from floral parts are different from those secreted by other parts of the plants[36]. According to Kuropka *et al.*[37], a very low amount of monoterpenes, almost unavailable was produced in *Achillea ptarmica* leaves, stems and roots essential oil, while the monoterpenes in floral parts were abundant. Similarly, the floral volatiles of *Lavandula pinnata* differed from the phytochemicals synthesized in the green parts (stems and leaves) during the flowering and vegetative phases[35].

Seasonal variation: The chemical constituent of phytochemicals changes with the season in some plant species, so harvesting at the right time is critical. *Crithmum maritimum* produced abundant sabinene compound when it was flowering, while γ-terpinene was the most abundantly produced phytochemical in other vegetative phase[38]. In addition, abundant Sesquiterpene was discovered in the essential oil of *Achillea millefolium* harvested during the vegetative phase while in plants harvested during the flowering phase, monoterpene was the most abundant constituent of the essential oil. A pure essential oil obtained from *Mentha piperita* contains a significant amount of menthol and ethanol, less than 4% menthofuran, and pulegone of less than 2%. When floral structures development reaches 50% (mid-to late August), the amount of the menthofuran increases with the yield of the essential oil while in September and October during over-maturation, the amount of oil yield tends to decrease with the amount of menthofuran and an increases, up to 60% in the amount of menthol[39].

Mechanical or chemical injuries: Under normal conditions, the plants produce a large amount of phytochemicals, which is considered constitutive production. When a plant experiences a traumatic injury, it may trigger de novo production, leading to the formation of new compounds that were not previously present. This process is referred to as induced production. The type of induced response stimulated is dependent on the species, its stage of development, water and sunlight availability. In *Picea* plant, the stem resin is produced in the canals of the axial resin in the cortex but the effect of injuries from mechanical activities, feeding from insects or fungal infection causes the accumulation of traumatic resin ducts within the developing xylem. Martin *et al.*[40] noticed very different morphological changes six to nine days after a spray treatment with methyl jasmonate (MeJA). The changes include denser cytoplasm and thin cell walls in xylem cells adjacent to the cambium, causing the development of more traumatic resin ducts. Visibility of the lumen of the traumatic canals was also observed fifteen days after treatment, which lead to the formation of a ring within the youngest xylem portion. Accumulation of resin in the lumen was also observed. The MeJA treatment increased the total accumulation of mono- and diterpenes in addition to inducing new canal development, but the absolute amount of sesquiterpenes remained unchanged.

Pollution: Although it is known that air pollution adversely impacts the production of secondary metabolite production, especially essential oil composition, it is difficult to assess because the observed results may be confused with responses to other stressors. Ozone is one of the most serious plant pollutants. Limited research has investigated the effects of air pollutants on the chemical composition of essential oils, with reported findings often being inconsistent and influenced by the specific type of pollutant involved[41]. Pollution from dust from roadsides, cement plants, and mining operations causes gloom, closure of the stoma, and reduction in the influx of CO_2.

Edaphic factors: Soil type and composition are determinant factors in secondary metabolite composition, particularly phytochemical composition. Many plant species rate of survival and growth are severely hampered in poorly aerated and drained soils, significantly reducing crop and essential oil yields and altering phytochemical composition. The addition of three nutrients (NPK) to the soil has resulted in an oil yield increase, however, the individual supplementation of these nutrients resulted in variations in both the composition and yield of the essential oils. Low Ca^{2+} levels can lead to the development of soils that are acidic which suppresses growth. Additionally, plant row spacing that is too close can have a negative impact due to allelopathic factors[42].

Genetic influence: Studies in genetics and hybridization have revealed that genes are a major determinant of the chemical constituent of essential oils. Research on the essential oils of various *Mentha* species indicates that the CC or Cc genotypes facilitated the transformation of -terpineol into limonene, which was then oxidized to produce carvone. Conversely, the cc genotype led to the production of menthadiene, which was subsequently converted into pulegone and menthol[43]. The processes driving the development of phytochemical production in plants involve several mechanisms: (a) Duplication of genes with subsequent divergence, where the original enzyme function is preserved A novel function arises as a result of gene duplication; (b) Convergent evolution, the independent emergence of similar functional traits across distinct evolutionary lineages; (c) Modification of an existing gene without gene duplication, resulting in the development of a novel enzymatic function, often resulting in a reduction or loss of the original function and (d) Complete loss of the function of the enzyme. These processes, in any of these cases, result in gene expression changes. Furthermore, few enzymatic structural changes can occur which can be increased via enzyme exposure to constitutive or inducible conditions. If new metabolite production provides an adaptive advantage for the plants, there is retention and an increase in metabolite production. Expression of protein changes may not always result in an enzyme loss, rather, they may cause the synthesis of secondary metabolites in a different vegetative or reproductive structure[35].

Storage: The storage method may also influence the amount of phytochemicals gotten from plants. Sunlight, moisture content, temperature, age, contaminations, oxidation, and other factors all have an impact on the yield and composition of phytochemicals. As stated previously, the secretory structure also influences the production and availability of phytochemicals. Secretory structures inside the plant are less susceptible to volatile losses while trichomes are more vulnerable to mechanical damage caused by transportation, and storage by crushing in piles. Species that show a yield decrease and phytochemicals composition changes with storage or drying are *Anethum graveolens*, *Cananga odorata*, *Carum carvi*, *Matricaria recutita*, *Jasminum grandiflorum*, *Narcissus poeticus*, *Ocimum basilicum*, *Sassafras albidum*, and *Zingiber officinale*[35].

Environmental changes: Thakore[44] stated that an element that remains beyond human control, is the environment. Essential oils and phytochemicals production is heavily influenced by weather conditions. Floods, droughts, cyclones, and hurricanes are examples of atmospheric conditions that have had varying degrees of severity for phytochemicals availability. According to Ileke *et al.*[45] stress caused by drought increased the total amount of resins and terpenes in the *Pinus sylvestris* plant. Drought stress was observed to be directly related to an increase in phytochemicals in species like *Artemisia dracunculus*, *Ocimum basilicum,* and *Anethum graveolens* whereas yield increases in *Artemisia annua*, *Coriandrum sativum*, and *Thymus vulgaris* were only achieved with normal or higher irrigation. Drought stress has been found to reduce photosynthetic rates and the uptake of nutrient such as sugar and carbon in plants. Monoterpene emission rates in *Pinus elliotii* increased exponentially with temperature, particularly those of myrcene and limonene between 20 and 46°C[46].

PLANT RESPONSES TO ENVIRONMENTAL CHANGES

Plant chemicals, such as primary and secondary metabolites, are very important in the interaction between plants and insects. The composition and concentration of plants secondary metabolites (PSM) in plant tissues as well as volatile emissions can be altered by changes in the environment through biosynthetic pathways changes and individual compound physiochemical properties. Recent studies have shown that increased temperature exert different effects on PSMs. An increase in total phenolics, including condensed tannins, flavonoids, saponins, and alkaloids, was observed in black locust (*Robinia pseudoacacia*) seedlings exposed to elevated temperatures[47]. Multiple studies have also reported increases in secondary metabolites, including lignin[48], saponins[49], and volatile terpenes[50], while others have shown decreases in PSMs, including condensed tannins[47] and lignin[51] under stress condition induced by warming. Additionally, increase in total phenolics such as some tannins and flavonoids were observed in some plants grown under increased CO_2 and O_3 condition[52]. Decrease in terpenoids content was observed under increased CO_2 and increased O_3 conditions[53]. Hormones in plants like ethylene influence plant chemical defenses in response to elevated CO_2 and O_3. The CO_2 enrichment tends to reduce jasmonic acid and ethylene regulated chemical defenses while increasing defenses that are dependent on salicylic acid. These chemical defense changes exert a negative, neutral or beneficial effect on plant-insects interaction[52], making it difficult to predict future changes in insect control. Increased salicylic acid biosynthesis and the upregulation of defense compounds such as some phenolic compounds involved in the shikimic acid pathway can be associated with increased O_3 levels[53]. A reduction in the production of phenols, flavonoids and terpenoids was observed in *Ficus insipida* leaf growing under a high O_3 environment.

IMPACT OF ENVIRONMENTAL CHANGES ON THE CHEMICAL COMPOUNDS OF SOME PLANTS COMMONLY USED FOR MOSQUITO CONTROL

Occurrences solely due to nature and anthropogenic activities cause drastic changes in the environment by transforming and transporting vast amounts of resources and power[54,55]. Natural systems capture solar energy to produce biomass, driving transformative processes by cycling matter through geological, biological, oceanic, and atmospheric pathways while humans use energy to satisfy their needs and desires. Historically, the impact of human activities on these natural processes was minimal. However, today, human actions are altering these flows on an unprecedented scale. Humans and natural processes fix almost as much nitrogen and Sulphur in the environment[56]. Fossil fuels burned by humans release vast amounts of carbon into the atmosphere which consequently disrupts the carbon cycle. Additionally, anthropogenic activities contribute to the release of metals like zinc, cadmium, nickel, mercury, arsenic, and vanadium at levels that are two times or more than those that are naturally occurring[57]. Environmental changes, which stem from a variety of sources, have become especially pronounced in recent centuries. One notable example is the increase in CO_2 concentrations, largely due to the burning of fuels and cement production[58]. From preindustrial levels of around 270-280 parts per million (ppm), carbon dioxide concentrations have now surged to over 374.9 ppm[59]. Over the past century, the Earth's climate has undergone an average warming of about 0.8°C, with a notable increase of 0.6°C occurring in the last three decades[58]. Environmental stress can disrupt various pathways of metabolism, leading to the generation of various metabolite byproducts. The UV-B, for example, causes changes in the phenylpropanoid biosynthetic pathway and the production of essential oils in *Curcuma* plants[60]. *Cornus officinalis* bioactive compound accumulation is entirely dependent on weather conditions[61].

***Azadirachta indica* and *Eucalyptus globulus* (neem and gum tree):** According to Akiode *et al.*[62], low temperatures increased the amount of alkaloid obtained from the neem and gum tree leaves and barks, while hot temperatures increased the amount of flavonoid obtained from these leaves. Under hot conditions, the phenol content of *Azadirachta indica* and *E. globulus* leaves was also significantly higher. Under high temperatures, neem bark produces a significant amount of phenol, whereas *E. globulus* bark and leaf produce a significant amount under optimum conditions. Akiode *et al.*[62] also reported that low temperatures produced significantly high amounts of saponin and tannin from both leaves and bark of Neem and gum trees while a remarkably low amount of tannin was discovered under hot conditions for both *Azadirachta indica* and *E. globulus*. Mckiernan *et al.*[63] reported no changes in terpenes and tannins content and a reduction in the total phenolic concentrations of gum tree exposed to drought stress, with leaves from plants in the moderate water treatment containing 17% less than controls, and leaves from low-water plants showing a 19% reduction in concentrations compared to controls with concentrations of tannins remaining unaffected by drought treatments.

***Allium sativum* (garlic):** Atif *et al.*[64] reported that extended daylight and increased temperature led to a greater accumulation of phenols which could influence the mosquitocidal properties of *Allium sativum*. Increased nutritional traits indicate that the bulbs developed under hot conditions, resulting not only in increased phenols but also in large amounts of proteins and sugars, which amplified their overall mosquitocidal properties. Higher growth temperatures led to an increase in total phenolics, flavonoids, soluble proteins, and sugars in garlic cultivars. Previous research has also associated elevated phenol levels with enhanced plant defense and growth protection[65]. Therefore, garlic bulbs grown in extended daylight and increased temperature conditions have higher insecticidal properties, which is an effective mosquito control measure. In addition to genetic factors, fluctuations in the environment also impact phenol levels[66]. Ecological factors have a stronger impact on phenolic content than genotypic variations[67]. Results indicated that garlic experiences a reduction in phenolic compounds under salinity-induced drought stress, as demonstrated by increased phenol leakage and a lower total phenolic content in stressed plants compared to controls[68].

Zanthoxylum species: Leaves of the Zanthoxylum species are more sensitive to seasonal fluctuations, including water stress, sunlight exposure, and developmental stages. The oil obtained from trunk bark has little chemical variability, which is likely due to the slow formation of trunk bark, which is less influenced by factors in the environment[69]. Tanoh *et al.*[70] reported that the composition of phytochemicals in Zanthoxylum varies due to climatic conditions, as certain compounds, which were previously present in only small amounts, were found in higher concentrations under certain conditions. Tanoh *et al.*[70] also discovered a decrease in tri dean-2-one production at low temperatures. This was also the case with e-ocimene, whose content was less than 4% at low temperatures but 23.57% at slightly lower temperatures. Undecan-2-one was also abundant at 8% at both low and high temperatures. Dendrolasin was found in significant amounts (4-16.4%) at both high and low temperatures, but not at slightly low temperatures. In the case of e-ocimene, 4% insignificant amount was observed at very low temperatures, while 23.57% was discovered at slightly low temperatures. They also discovered 13.30% thymol, an oxygenated monoterpene, at high temperatures. Higher temperatures are associated with large amounts of Limonene and Copaene. On the other hand, cooler temperatures with minimal fluctuations encourage the production of Linalool. In the same environment, compounds like α-Terpineol, Caryophyllene, L-α-Terpineol, Terpinolene, α-Phellandren, d-Limonene, and Geranyl acetate are a lot sensitive to ecological factors, while β-Pinene and Limonene levels are less influenced by climatic variables[71].

***Jatropha curcas* (barbados nut):** Barbados nut plant has been discovered to be toxic to insects, microbes and parasites[72]. The crude leaf extract of *Jatropha curcas* extracted with petroleum ether demonstrated larvicidal activity against vector mosquitoes, including Culex, Anopheles and Aedes mosquito[73]. Leaves of *Jatropha curcas* has been reported to exhibit variation in terms of tannins, phenolic compounds, and amino acids when subjected to different temperatures. Maximum levels of these compounds were found in leaves collected under high temperatures and least under low temperatures however, phytic acid contents were greater under low temperatures[74]. Iwuala *et al.*[75] reported low levels of alkaloid, flavonoids, tannins and steroids contents in *J. curcas* plants exposed to drought conditions while an increase in saponin content was recorded.

***Ocimum gratissimum* (holy basil):** Seasonal changes influenced the compounds of essential oils in *Ocimum* plants[76], while variations in *Ocimum gratissimum* were linked to the time of day[77]. The phenyl-propanoid eugenol and the monoterpene 1,8-cineole concentrations were highest at low and high temperatures. Low temperatures promote the production of sesquiterpene components, whereas high temperatures produced no monoterpene linalool. The study's findings revealed that the highest essential content of phytochemicals was produced at low temperatures. High temperatures resulted in the lowest percentage. In terms of plant parts, the leaves had the largest amount of essential oil, followed by the inflorescence. The stem had the lowest concentration of essential oil phytochemicals. The chemical constituent limonene has a highly variable behavior at different temperatures. The highest value was obtained at a low temperature. This is similar to the phytochemicals eugenol and linalool, which were also produced in high amounts at low temperatures and low amounts at high temperatures. The chemical constituent methyl chavicol is highly favoured by slightly low temperatures while the lowest value was recorded under high temperatures. The camphor content was slightly affected by the changed seasons with comparisons to other chemical constituents[78]. According to Rahimi *et al.*[79], drought stress increased the content of phenolic and flavonoid compounds in basil. Essential oil composition changes change with drought stress with the conversion of some compounds into others, a decrease of some compounds, and an increase for others. For example, increases in linalool and 1.8-cineol, with a decrease in the geranial compound. The amount of methyl chavicol was also observed to increase with increased drought stress.

CONSEQUENCES OF THE CHEMICAL COMPOSITION CHANGES ON MOSQUITO CONTROL AND THE ENVIRONMENT

Altered mosquito-repelling properties: Changes in phytochemistry have an impact on the repellent properties of these plants. Many of these plants are effective because of phytochemicals, serving a vital role in their activities against mosquitoes. However, as environmental conditions change, the production and concentration of these bioactive compounds are influenced. Changes in temperature, precipitation patterns, and exposure to elevated levels of solar rays, for example, have an impact on the synthesis and efficacy of these phytochemicals. These chemical changes in mosquito-repelling plants can result in a reduced ability to repel mosquitos effectively[80].

Increased disease transmission: Reduction in the efficacy of mosquito control measures heightens the likelihood of disease transmission, especially in mosquito-borne disease endemic areas. In regions heavily impacted by diseases transmitted by mosquitoes, any reduction in the efficacy of mosquito control measures has the potential to worsen the existing public health challenges. Reduced ability to repel or deter mosquitoes may result in increased human-mosquito interactions, potentially increasing disease transmission[81].

Public health inequities: Inconsistent mosquito control measures may inadvertently worsen disparities in community health outcomes due to the shifting variety of plants that repel mosquitoes and how well they work. This is especially true in areas that are endemic with diseases vectorized by mosquitoes and where the effectiveness of mosquito control measures can signify the difference between health and illness. Communities dealing with public health disparities frequently bear the brunt of these challenges. Inconsistent mosquito control measures can increase exposure to mosquito-borne diseases, affecting vulnerable populations disproportionately. Socioeconomic factors, healthcare access, and environmental conditions can all exacerbate these disparities. For example, marginalized communities with limited access to healthcare resources may be less prepared to manage and treat mosquito-borne diseases, resulting in worse health outcomes[82].

Increased reliance on chemical insecticides: Changes in the phytochemicals of mosquitocidal plants can increase reliance on chemical insecticides if these plants fail to control mosquitoes. Synthetic insecticides, while effective in curbing mosquito populations and reducing disease transmission, are not without their drawbacks. One significant concern is their environmental impact. The application of these chemicals can lead to consequences, such as water pollution, disruption of non-target species, and the development of insecticide resistance in mosquito populations. These consequences can resonate throughout ecosystems, causing imbalances and more environmental challenges. Prolonged or improper exposure to these chemicals can result in adverse health effects, including skin irritations, respiratory problems, and, in extreme cases, more severe health conditions[83].

Environmental degradation: The increased reliance on chemical insecticides as a primary tool in mosquito control strategies has destructive environmental consequences. The contamination of water bodies, via wash-off and effluents from chemicals can occur when they are carried into nearby streams, rivers, and lakes by runoff from treated areas, resulting in water pollution. This contamination affects not only aquatic life but also the quality of drinking water. Chemical insecticides cause further disruption in ecosystems, affecting beneficial microorganisms in soil and aquatic environments. These microorganisms are important for nutrient cycling, soil fertility, and ecological balance. Their disruption can cause ecosystem imbalances, threatening not only the environment's health but also its ability to support life and biodiversity. The persistence of chemical insecticides in the environment is one of the most harmful long-term consequences. These chemicals can remain in the soil, water, and air for long periods, accumulating over time. This persistence can result in chronic environmental degradation, with consequences that may not be immediately apparent but may emerge years or decades later[84].

Emerging disease hotspot: Changes in the chemical composition of mosquitocidal plants can create an environment that is more conducive to mosquito breeding. These plants' phytochemicals may become less effective at repelling or deterring mosquitoes as they evolve in response to changing weather patterns. As a result, mosquitoes may become more prevalent in areas where these plants were once a natural barrier to their development. Such changes can lead to the establishment of new mosquito breeding grounds, contributing to the emergence of disease hotspots. With increased mosquito populations, the risk of disease transmission increases, and regions previously thought to be low-risk for mosquito-borne illnesses may now face an increased threat[81].

WAYS OF MITIGATING THESE EFFECTS FOR EFFECTIVE PLANT BASED CONTROL

Plant breeding: This involves the development of breeding programs to select and propagate mosquitocidal plant varieties with a genetic makeup that allows them to withstand the various stressors associated with changes in the environment, including shifts in temperatures precipitation patterns and pest pressures. Not only does breeding for resilience protect the efficacy of mosquito control, but it also contributes to more sustainable and environmentally friendly mosquito management. This involves breeding plants with increased drought tolerance, enhanced photosynthetic efficiency, and the capacity to produce robust levels of phytochemicals in response to varying temperature and light conditions[85].

Selective pruning: Selective pruning is a valuable horticultural technique used to maximize the production of plant parts with desired chemical compositions. This practice is critical in mosquito control because it ensures the availability of plant materials high in phytochemicals known to repel mosquitos. Selective pruning allows for the long-term and targeted enhancement of phytochemical content, providing a versatile and environmentally friendly approach to improving the efficacy of mosquito control strategies. Selective pruning involves removing specific plant parts' carefully, such as leaves, stems, or branches, to improve other plant parts growth with the desired phytochemical composition. This is done in a bid to direct the plant's growth materials toward the production of phytochemicals with insecticidal or mosquito-repelling properties, such as alkaloids, terpenoids, phenolics, and essential oils[86].

Microclimate control: It involves the creation of local environments with optimum resources needed to nurture these plants. Microclimate control shields plants from the adverse effects of extreme weather events and temperature variations by managing the immediate environment surrounding them. This involves manipulating factors like temperature, humidity, and light exposure within a confined area. Methods of microclimate control include greenhouses, shade structures, or rain shelters which protect plants against these extreme weather conditions. Methods like heating, cooling, and insulation can be used to maintain an optimal temperature condition. Also, misting systems, irrigation control, and humidity sensors are some methods that enable growers to maintain the ideal humidity conditions for mosquitocidal plants. Light exposure can also be regulated with the use of shade nets, artificial lighting, or adjustable shading systems which helps to protect plants from overexposure to radiation while receiving an optimal amount of sunlight[87].

Permaculture: Permaculture involves imitating natural ecosystems. It aims to replicate functional relationships by observing how ecosystems function such as inter-cropping, integrating plants and animals, and incorporating beneficial interactions within the system. Companion planting, for example, is a common permaculture practice in which plants mutually beneficial plant species together to optimize ecological functions and increase resilience. Additionally, permaculture often incorporates swales and terraces to manage the flow of water during heavy rainfall, preventing soil erosion and flooding. These practices safeguard agricultural productivity and minimize damage caused by harsh environmental conditions[88].

Conservation tillage: It is a practice that involves the deliberate reduction or elimination of traditional tillage, which is the mechanical preparation of soil through plowing or digging before planting. The retention of soil moisture is important for crop growth and agricultural sustainability during drought. Conservation tillage helps achieve this by reducing soil disruption. Traditional tillage breaks up soil structure, increasing the rate of water evaporation and reducing the soil's ability to retain moisture while conservation tillage leaves crop residues on the field's surface, providing a natural mulch that acts as a barrier against water loss. This organic mulch shields the soil from direct sunlight reduces evaporation and helps maintain consistent soil moisture levels, ensuring that crops have optimum water availability[85].

CONCLUSION

Mosquitocidal plants, known for their natural mosquito-repellent, adulticidal, and larvicidal properties, face threats from environmental changes like rising temperatures, UV-B radiation, elevated CO_2, and pollution, disrupting phytochemical biosynthesis. These disruptions reduce their efficacy, increasing reliance on chemical insecticides and environmental degradation. Future research should focus on understanding environmental stressors' effects on phytochemicals, developing resilient plant varieties, adaptive cultivation practices, and leveraging biotechnological tools. Promoting sustainable cultivation and community involvement is vital to preserving their role in pest management and public health.

SIGNIFICANCE STATEMENT

This study highlights the critical role of mosquitocidal plants in sustainable mosquito control and their reliance on phytochemical efficacy, which is increasingly threatened by environmental changes. By examining the impacts of factors such as climate change, pollution, and anthropogenic activities on phytochemical production, the study provides valuable insights into the vulnerabilities of these plants. The findings reveal the urgent need for adaptive strategies to reduce environmental stressors and ensure the continued utility of mosquitocidal plants as eco-friendly alternatives to chemical insecticides. Furthermore, the study emphasizes the importance of integrating scientific advancements, sustainable cultivation practices, and community engagement in preserving the efficacy of these plants. This research holds significant implications for global public health, environmental conservation, and the development of resilient pest management systems in the face of changing environmental conditions.

REFERENCES

1. Mordecai, E.A., S.J. Ryan, J.M. Caldwell, M.M. Shah and A.D. LaBeaud, 2020. Climate change could shift disease burden from malaria to arboviruses in Africa. Lancet Planet. Health, 4: E416-E423.
2. Richards, S.L., B.D. Byrd, M.H. Reiskind and A.V. White, 2020. Assessing insecticide resistance in adult mosquitoes: Perspectives on current methods. Environ. Health Insights, Vol. 14. 10.1177/1178630220952790.
3. Barillas-Mury, C., R. Graf, H.H. Hagedorn and M.A. Wells, 1991. cDNA and deduced amino acid sequence of a blood meal-induced trypsin from the mosquito, *Aedes aegypti*. Insect Biochem., 21: 825-831.
4. Innocent, E., C.C. Joseph, N.K. Gikonyo, M.H.H. Nkunya and A. Hassanali, 2010. Constituents of the essential oil of *Suregada zanzibariensis* leaves are repellent to the mosquito, *Anopheles gambiae* s.s. J. Insect Sci., Vol. 10. 10.1673/031.010.5701.
5. Gershenzon, J. and N. Dudareva, 2007. The function of terpene natural products in the natural world. Nat. Chem. Biol., 3: 408-414.
6. Wina, E., S. Muetzel and K. Becker, 2005. The impact of saponins or saponin-containing plant materials on ruminant production-A review. J. Agric. Food Chem., 53: 8093-8105.
7. Ahuja, I., R.C.H. de Vos, A.M. Bones and R.D. Hall, 2010. Plant molecular stress responses face climate change. Trends Plant Sci., 15: 664-674.
8. Shaalan, E.A.S., D. Canyon, M.W.F. Younes, H. Abdel-Wahab and A.H. Mansour, 2005. A review of botanical phytochemicals with mosquitocidal potential. Environ. Int., 31: 1149-1166.
9. Andrade-Ochoa, S., D. Sánchez-Aldana, K.F. Chacón-Vargas, B.E. Rivera-Chavira and L.E. Sánchez-Torres *et al*., 2018. Oviposition deterrent and larvicidal and pupaecidal activity of seven essential oils and their major components against *Culex quinquefasciatus* say (Diptera: Culicidae): Synergism-antagonism effects. Insects, Vol. 9. 10.3390/insects9010025.
10. Vera, S.S., D.F. Zambrano, S.C. Méndez-Sanchez, F. Rodríguez-Sanabria, E.E. Stashenko and J.E.D. Luna, 2014. Essential oils with insecticidal activity against larvae of *Aedes aegypti* (Diptera: Culicidae). Parasitol. Res., 113: 2647-2654.
11. Warikoo, R., N. Wahab and S. Kumar, 2011. Oviposition-altering and ovicidal potentials of five essential oils against female adults of the dengue vector, *Aedes aegypti* L. Parasitol. Res., 109: 1125-1131.
12. Ileke, K.D. and I.O. Olabimi, 2019. Insecticidal activities of *Chromolaena odorata* and *Vernonia amygdalina* leaf extracts against *Anopheles gambiae* [Diptera: Culicidae]. Int. J. Trop. Dis., Vol. 2. 10.23937/ijtd-2017/1710018.
13. Al-Mekhlafi, F.A., 2018. Larvicidal, ovicidal activities and histopathological alterations induced by *Carum copticum* (Apiaceae) extract against *Culex pipiens* (Diptera: Culicidae). Saudi J. Biol. Sci., 25: 52-56.
14. Jankowska, M., J. Rogalska, J. Wyszkowska and M. Stankiewicz, 2018. Molecular targets for components of essential oils in the insect nervous system-A review. Molecules, Vol. 23. 10.3390/molecules23010034.
15. Pavela, R., 2015. Essential oils for the development of eco-friendly mosquito larvicides: A review. Ind. Crops Prod., 76: 174-187.
16. Pitarokili, D., A. Michaelakis, G. Koliopoulos, A. Giatropoulos and O. Tzakou, 2011. Chemical composition, larvicidal evaluation, and adult repellency of endemic Greek *Thymus* essential oils against the mosquito vector of West Nile virus. Parasitol. Res., 109: 425-430.
17. Tabari, M.A., M.R. Youssefi, A. Esfandiari and G. Benelli, 2017. Toxicity of β-citronellol, geraniol and linalool from *Pelargonium roseum* essential oil against the West Nile and filariasis vector *Culex pipiens* (Diptera: Culicidae). Res. Vet. Sci., 114: 36-40.
18. Winnacker, M. and B. Rieger, 2015. Recent progress in sustainable polymers obtained from cyclic terpenes: Synthesis, properties, and application potential. ChemSusChem, 8: 2455-2471.

19. Duplais, C., N. Papon and V. Courdavault, 2020. Tracking the origin and evolution of plant metabolites. Trends Plant Sci., 25: 1182-1184.
20. Cantrell, C.L., J.A. Klun, J. Pridgeon, J. Becnel, S. Green III and F.R. Fronczek, 2009. Structure-activity relationship studies on the mosquito toxicity and biting deterrency of callicarpenal derivatives. Chem. Biodivers., 6: 447-458.
21. Gutiérrez-Grijalva, E.P., L.X. López-Martínez, L.A. Contreras-Angulo, C.A. Elizalde-Romero and J.B. Heredia, 2020. Plant Alkaloids: Structures and Bioactive Properties. In: Plant-Derived Bioactives: Chemistry and Mode of Action, Swamy, M.K. (Ed.), Springer, Singapore, ISBN: 978-981-15-2361-8, pp: 85-117.
22. Ahmed, N., M. Alam, M. Saeed, Hidayat Ullah and T. Iqbal *et al*., 2021. Botanical Insecticides Are a Non-Toxic Alternative to Conventional Pesticides in the Control of Insects and Pests. In: Global Decline of Insects, El-Shafie, H.A.F. (Ed.), IntechOpen, London, United Kingdom, ISBN: 978-1-83969-588-9.
23. Bekele, D., 2018. Review on insecticidal and repellent activity of plant products for malaria mosquito control. Biomed. Res. Rev., Vol. 2. 10.15761/BRR.1000114.
24. Elimam, A.M., K.H. Elmalik and F.S. Ali, 2009. Larvicidal, adult emergence inhibition and oviposition deterrent effects of foliage extract from *Ricinus communis* L. against *Anopheles arabiensis* and *Culex quinquefasciatus* in Sudan. Trop. Biomed., 26: 130-139.
25. Wachira, S.W., S. Omar, J.W. Jacob, M. Wahome and H.T. Alborn *et al*., 2014. Toxicity of six plant extracts and two pyridone alkaloids from *Ricinus communis* against the malaria vector *Anopheles gambiae*. Parasites Vectors, Vol. 7. 10.1186/1756-3305-7-312.
26. Kim, S.I. and Y.J. Ahn, 2017. Larvicidal activity of lignans and alkaloid identified in *Zanthoxylum piperitum* bark toward insecticide-susceptible and wild *Culex pipiens pallens* and *Aedes aegypti*. Parasites Vectors, Vol. 10. 10.1186/s13071-017-2154-0.
27. Velu, K., D. Elumalai, P. Hemalatha, M. Babu, A. Janaki and P.K. Kaleena, 2015. Phytochemical screening and larvicidal activity of peel extracts of *Arachis hypogaea* against chikungunya and malarial vectors. Int. J. Mosq. Res., 2: 1-8.
28. Isman, M.B., 2006. Botanical insecticides, deterrents and repellents in modern agriculture and an increasingly regulated world. Annu. Rev. Entomol., 51: 45-66.
29. Ghosh, A., N. Chowdhury and G. Chandra, 2008. Laboratory evaluation of a phytosteroid compound of mature leaves of Day Jasmine (Solanaceae: Solanales) against larvae of *Culex quinquefasciatus* (Diptera: Culicidae) and nontarget organisms. Parasitol. Res., 103: 271-277.
30. Chowdhury, N., S.K. Chatterjee, S. Laskar and G. Chandra, 2009. Larvicidal activity of *Solanum villosum* Mill (Solanaceae: Solanales) leaves to *Anopheles subpictus* Grassi (Diptera: Culicidae) with effect on non-target *Chironomus circumdatus* Kieffer (Diptera: Chironomidae). J. Pest Sci., 82: 13-18.
31. Abdul Rahuman, A., G. Gopalakrishnan, P. Venkatesan and K. Geetha, 2008. Isolation and identification of mosquito larvicidal compound from *Abutilon indicum* (Linn.) sweet. Parasitol. Res., 102: 981-988.
32. Banerjee, S., S. Singha, S. Laskar and G. Chandra, 2011. Efficacy of *Limonia acidissima* L. (Rutaceae) leaf extract on larval immatures of *Culex quinquefasciatus* Say 1823. Asian Pac. J. Trop. Med., 4: 711-716.
33. Wentzell, A.M., I. Boeye, Z. Zhang and D.J. Kliebenstein, 2008. Genetic networks controlling structural outcome of glucosinolate activation across development. PLoS Genet., Vol. 4. 10.1371/journal.pgen.1000234.
34. Bouwman, H., H. van den Berg and H. Kylin, 2011. DDT and malaria prevention: Addressing the paradox. Environ. Health Perspect., 119: 744-747.
35. Figueiredo, A.C., J.G. Barroso, L.G. Pedro and J.J.C. Scheffer, 2008. Factors affecting secondary metabolite production in plants: Volatile components and essential oils. Flavour Fragrance J., 23: 213-226.
36. Novak, J., L. Draxler, I. Göhler and C.M. Franz, 2005. Essential oil composition of *Vitex agnus-castus*-comparison of accessions and different plant organs. Flavour Fragrance J., 20: 186-192.

37. Kuropka, G., M. Neugebauer and K.W. Glombitza, 1991. Essential oils of *Achillea ptarmica*. Planta Med., 57: 492-494.
38. Ileke, K.D., E.T. Obimakinde, C.M. Anthony and J.O. Olayinka-Olagunju, 2019. Efficacy of *Tithonia diversifolia* and *Momordica charantia* leaves extracts against malaria vector, *Anopheles gambiae* Gile (Diptera: Culicidae). Int. J. Trop. Dis. Health, Vol. 36. 10.9734/ijtdh/2019/v36i230139.
39. Ranson, H., R. N'Guessan, J. Lines, N. Moiroux, Z. Nkuni and V. Corbel, 2011. Pyrethroid resistance in African anopheline mosquitoes: What are the implications for malaria control? Trends Parasitol., 27: 91-98.
40. Martin, D.M., J. Gershenzon and J. Bohlmann, 2003. Induction of volatile terpene biosynthesis and diurnal emission by methyl jasmonate in foliage of Norway spruce. Plant Physiol., 132: 1586-1599.
41. Judzentiene, A., A. Stikliene and E. Kupcinskiene, 2007. Changes in the essential oil composition in the needles of scots pine (*Pinus sylvestris* L.) under anthropogenic stress. Sci. World J., 7: 141-150.
42. Taylor-Wells, J., B.D. Brooke, I. Bermudez and A.K. Jones, 2015. The neonicotinoid imidacloprid, and the pyrethroid deltamethrin, are antagonists of the insect Rdl GABA receptor. J. Neurochem., 135: 705-713.
43. Nemeth, E., 2005. Essential oil composition of species in the genus *Achillea*. J. Essent. Oil Res., 17: 501-512.
44. Thakore, Y., 2006. The biopesticide market for global agricultural use. Ind. Biotechnol., 2: 194-208.
45. Ileke, K.D., B.W. Adu and I.O. Olabimi, 2021. Bioefficacy of two indigenous Nigerian botanicals on the developmental stages of malaria vector, *Anopheles gambiae* Giles [Diptera: Culicidae]. Int. J. Trop. Insect Sci., 41: 999-1010.
46. Tyagi, B.K., 2016. Advances in Vector Mosquito Control Technologies, with Particular Reference to Herbal Products. In: Herbal Insecticides, Repellents and Biomedicines: Effectiveness and Commercialization, Veer, V. and R. Gopalakrishnan (Eds.), Springer, New Delhi, India, ISBN: 978-81-322-2704-5, pp: 1-9.
47. Zhao, Y.H., X. Jia, W.K. Wang, T. Liu, S.P. Huang and M.Y. Yang, 2016. Growth under elevated air temperature alters secondary metabolites in *Robinia pseudoacacia* L. seedlings in Cd- and Pb-contaminated soils. Sci. Total Environ., 565: 586-594.
48. Ileke, K.D., O.I. Omotayo, A.V. Akeju and A.M. Iwakun, 2022. Bioefficacy of leaf extracts of two underutilized ferns, *Azolla pinnata* and *Polystichum acrostichoides* against malaria vector, *Anopheles gambiae* Giles [Diptera: Culicidae]. Niger. J. Entomol., 38: 50-64.
49. Ileke, K.D., J.M. Adesina, A.O. Adeoye and I.O. Olabimi, 2020. Biopesticides activity of three medicinal plants extracts on the developmental stages of malaria vector, *Anopheles gambiae* Giles (Diptera: Culicidae). Iran. J. Health Sci., 8: 1-9.
50. Kivimäenpää, M., R.P. Ghimire, S. Sutinen, E. Häikiö, A. Kasurinen, T. Holopainen and J.K. Holopainen, 2016. Increases in volatile organic compound emissions of Scots pine in response to elevated ozone and warming are modified by herbivory and soil nitrogen availability. Eur. J. For. Res., 135: 343-360.
51. Jamieson, M.A., E.G. Schwartzberg, K.F. Raffa, P.B. Reich and R.L. Lindroth, 2015. Experimental climate warming alters aspen and birch phytochemistry and performance traits for an outbreak insect herbivore. Global Change Biol., 21: 2698-2710.
52. Zavala, J.A., L. Gog and R. Giacometti, 2017. Anthropogenic increase in carbon dioxide modifies plant-insect interactions. Ann. Appl. Biol., 170: 68-77.
53. Ode, P.J., S.N. Johnson and B.D. Moore, 2014. Atmospheric change and induced plant secondary metabolites-are we reshaping the building blocks of multi-trophic interactions? Curr. Opin. Insect Sci., 5: 57-65.
54. Schneider, G.F., A.W. Cheesman, K. Winter, B.L. Turner, S. Sitch and T.A. Kursar, 2017. Current ambient concentrations of ozone in Panama modulate the leaf chemistry of the tropical tree *Ficus insipida*. Chemosphere, 172: 363-372.

55. Vitousek, P.M., P.R. Ehrlich, A.H. Ehrlich and P.A. Matson, 1986. Human appropriation of the products of photosynthesis. BioScience, 36: 368-373.
56. Graedel, T.E. and P.J. Crutzen, 1989. The changing atmosphere. Sci. Am., 261: 58-69.
57. Nriagu, J.O. and J.M. Pacyna, 1988. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature, 333: 134-139.
58. Olabimi, I.O., K.D. Ileke, B.W. Adu and T.E. Arotolu, 2021. Potential distribution of the primary malaria vector *Anopheles gambiae* Giles [Diptera: Culicidae] in Southwest Nigeria under current and future climatic conditions. J. Basic Appl. Zool., Vol. 82. 10.1186/s41936-021-00261-8.
59. Ileke, K.D. and I.O. Olabimi, 2019. Bioengineering of malaria vectors, anopheles mosquitoes (Diptera: Culicidae) as a control strategy: An overview. Braz. J. Biol. Sci., 6: 27-38.
60. Jaiswal, D. and S.B. Agrawal, 2021. Ultraviolet-B induced changes in physiology, phenylpropanoid pathway, and essential oil composition in two *Curcuma* species (*C. caesia* Roxb. and *C. longa* L.). Ecotoxicol. Environ. Saf., Vol. 208. 10.1016/j.ecoenv.2020.111739.
61. Xue, Y., B. Cao, H. Liang, J. Yang and P. Gao *et al*., 2021. Environmental shifts have important impacts on the functional traits and bioactive products of medicinal crop *Cornus officinalis*. Ind. Crops Prod., Vol. 162. 10.1016/j.indcrop.2021.113304.
62. Akiode, S.O., A.E. Fadeyi, A.A. Ibi and M.B. Hassan, 2021. Effect of seasonal changes on the quantity of secondary metabolites from neem and eucalyptus plants in North Central Nigeria. World J. Biol. Pharm. Health Sci., 7: 43-52.
63. McKiernan, A.B., M.J. Hovenden, T.J. Brodribb, B.M. Potts, N.W. Davies and J.M. O'Reilly-Wapstra, 2014. Effect of limited water availability on foliar plant secondary metabolites of two *Eucalyptus* species. Environ. Exp. Bot., 105: 55-64.
64. Atif, M.J., B. Amin, M.I. Ghani, M. Ali and Z. Cheng, 2020. Variation in morphological and quality parameters in garlic (*Allium sativum* L.) bulb influenced by different photoperiod, temperature, sowing and harvesting time. Plants, Vol. 9. 10.3390/plants9020155.
65. Egigu, M.C., M.A. Ibrahim, J. Riikonen, A. Yahya, T. Holopainen, R. Julkunen-Tiitto and J.K. Holopainen, 2014. Effects of rising temperature on secondary compounds of Yeheb (*Cordeauxia edulis* Hemsley). Am. J. Plant Sci., 5: 517-527.
66. Ma, D., Y. Li, J. Zhang, C. Wang and H. Qin *et al*., 2016. Accumulation of phenolic compounds and expression profiles of phenolic acid biosynthesis-related genes in developing grains of white, purple, and red wheat. Front. Plant Sci., Vol. 7. 10.3389/fpls.2016.00528.
67. Mpofu, A., H.D. Sapirstein and T. Beta, 2006. Genotype and environmental variation in phenolic content, phenolic acid composition, and antioxidant activity of hard spring wheat. J. Agric. Food Chem., 54: 1265-1270.
68. Astaneh, R.K., S. Bolandnazar and F.Z. Nahandi, 2022. Exogenous nitric oxide protect garlic plants against oxidative stress induced by salt stress. Plant Stress, Vol. 5. 10.1016/j.stress.2022.100101.
69. Geng, S., Z. Cui, X. Huang, Y. Chen, D. Xu and P. Xiong, 2011. Variations in essential oil yield and composition during *Cinnamomum cassia* bark growth. Ind. Crops Prod., 33: 248-252.
70. Tanoh, E.A., G.B. Boué, F. Nea, M. Genva and E.L. Wognin *et al*., 2020. Seasonal effect on the chemical composition, insecticidal properties and other biological activities of *Zanthoxylum leprieurii* Guill. & Perr. essential oils. Foods, Vol. 9. 10.3390/foods9050550.
71. Wu, Y., Z. Zhuo, Q. Qian and D. Xu, 2024. Chemotaxonomic variation of volatile components in *Zanthoxylum bungeanum* peel and effects of climate on volatile components. BMC Plant Biol., Vol. 24. 10.1186/s12870-024-05485-8.
72. Lin, J., X. Zhou, J. Wang, P. Jiang and K. Tang, 2010. Purification and characterization of curcin, a toxic lectin from the seed of *Jatropha curcas*. Prep. Biochem. Biotechnol., 40: 107-118.
73. Sakthivadivel, M. and T. Daniel, 2008. Evaluation of certain insecticidal plants for the control of vector mosquitoes viz. *Culex quinquefasciatus*, *Anopheles stephensi* and *Aedes aegypti*. Appl. Entomol. Zool., 43: 57-63.

74. Tomar, N.S., M. Sharma and R.M. Agarwal, 2015. Phytochemical analysis of *Jatropha curcas* L. during different seasons and developmental stages and seedling growth of wheat (*Triticum aestivum* L) as affected by extracts/leachates of *Jatropha curcas* L. Physiol. Mol. Biol. Plants, 21: 83-92.
75. Iwuala, E.N., R.N. Kanu and C.N. Eze, 2015. Effects of salinity and drought on the phytochemical production in *Jatrophacurcas* L. Bayero J. Pure Appl. Sci., 8: 81-79.
76. Moraes, L.A.S., R. Facanali, M.O.M. Marques, L.C. Ming and M.A.A. Meireles, 2002. Phytochemical characterization of essential oil from *Ocimum selloi*. Ann. Braz. Acad. Sci., 74: 183-186.
77. de Vasconcelos Silva, M.G., A.A Craveiro, F.J.A. Matos, M.I.L. Machado and J.W. Alencar, 1999. Chemical variation during daytime of constituents of the essential oil of *Ocimum gratissimum* leaves. Fitoterapia, 70: 32-34.
78. Kumar, A. and R.K. Lal, 2022. The consequence of genotype × environment interaction on high essential oil yield and its composition in clove basil (*Ocimum gratissimum* L.). Acta Ecol. Sin., 42: 633-640.
79. Rahimi, M., M. Mortazavi, A. Mianabadi and S. Debnath, 2023. Evaluation of basil (*Ocimum basilicum*) accessions under different drought conditions based on yield and physio-biochemical traits. BMC Plant Biol., Vol. 23. 10.1186/s12870-023-04554-8.
80. Demirak, M.Ş.Ş. and E. Canpolat, 2022. Plant-based bioinsecticides for mosquito control: Impact on insecticide resistance and disease transmission. Insects, Vol. 13. 10.3390/insects13020162.
81. Onen, H., M.M. Luzala, S. Kigozi, R.M. Sikumbili and C.J.K. Muanga *et al*., 2023. Mosquito-borne diseases and their control strategies: An overview focused on green synthesized plant-based metallic nanoparticles. Insects, Vol. 14. 10.3390/insects14030221.
82. Naserrudin, N.A., P.Y.P. Lin, A. Monroe, S.E. Baumann and B. Adhikari *et al*., 2023. Disentangling the intersection of inequities with health and malaria exposure: Key lessons from rural communities in Northern Borneo. Malar. J., Vol. 22. 10.1186/s12936-023-04750-9.
83. Kim, K.H., Ehsanul Kabir and S.A. Jahan, 2017. Exposure to pesticides and the associated human health effects. Sci. Total Environ., 575: 525-535.
84. Rani, L., K. Thapa, N. Kanojia, N. Sharma and S. Singh *et al*., 2021. An extensive review on the consequences of chemical pesticides on human health and environment. J. Cleaner Prod., Vol. 283. 10.1016/j.jclepro.2020.124657.
85. Brown, J. and P. Caligari, 2011. An Introduction to Plant Breeding. John Wiley & Sons, Hoboken, New Jersey, ISBN: 9781444357707, Pages: 224.
86. Hotegni, V.N.F., W.J.M. Lommen, E.K. Agbossou and P.C. Struik, 2015. Selective pruning in pineapple plants as means to reduce heterogeneity in fruit quality. SpringerPlus, Vol. 4. 10.1186/s40064-015-0907-9.
87. Kutta, E. and J. Hubbart, 2014. Improving understanding of microclimate heterogeneity within a contemporary plant growth facility to advance climate control and plant productivity. J. Plant Sci., 2: 167-178.
88. Ferguson, R.S. and S.T. Lovell, 2014. Permaculture for agroecology: Design, movement, practice, and worldview. A review. Agron. Sustainable Dev., 34: 251-274.