Hydroponics culture regulated metabolic variations in plants of medicinal value

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Abstract

The current review chiefly brings to light the importance of alternative cultivation strategies for medicinal plants about the effective enhancement of the bioactive substances. The fast-paced society is favoring the need for its cost-effective cultivation and studying the effects thereafter. The mis-steps while collecting the plant from the wild lead to identification issues, genetic and phenotypic variations, variable bioactive substances/secondary metabolites, and toxic compounds. So, cultivation happening in controlled environments, Hydroponics and its attributed advantages help to alleviate the losses and knowledge assimilation. The increasing popularity of Hydroponics reaching the foothills of herbal cultivation, other than vegetables and fruits, ornamentals is a step in the right direction, moreover enhancing the concentration of bioactive substances by altering the metabolic fluxes. A huge economic advantage accrued through hydroponics can generate millions of jobs for the jobless and ease of operation which can be easily understood by the farmer community. However, the limits of the technique are low germination rate and artificial monitoring which weighs down the scale when compared with the uniform yields, produced from the plants. The commercial success of cultivating medicines in your backyard can be a future in the pipeline. These metabolic changes in response to abiotic environmental factors are discussed in detail. Thus, Hydroponics helps maintain the diversity of the plant species and the spontaneity of the flora while the major challenge is the altered metabolic profile of the plants. The regulation of the synergistic effect of medicinal plants has to be conclusively determined, with the help of biotechnological and smart IT solutions.

Keywords: Hydroponics, metabolic flux, plants, plant tissue culture, eco-metabolomics research, light intensity, nutrients, carbon, nitrogen

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Introduction

The production of plants in lieu of their compounds of interest has been deciphered lately by mankind. The scientific fraternity has been largely focusing on methods to improve upon the nutritional worth in terms of crop yield which itself is an enormous task. To comprehend it, one has to develop a temperament to realize the fervor and rigor of plant biological processes. The mesh/network of these processes regulates the metabolite synthesis of primary and secondary importance [1]. These processes regulate cellular mechanisms and are operationalized based on their induction, however, complex in character and compartmentalized in different plant organelles sharing metabolic intermediates and cofactors. These processes render plants to adapt to biotic and abiotic stresses and lead to the normal functioning of the plant and its produce. However, biotechnological approaches to direct the metabolic fluxes have been arising to exploit the plant for the desired primary and secondary metabolism [1]. The primary pathways being glycolysis, pentose-phosphate pathway (PPP), anaplerotic reactions, and tricarboxylic acid (TCA) cycle [2]. Nowadays, these fluxes are quantified and involved in the primary metabolism to help metabolomics in providing the eagle's eye to academicians and researchers [1].

The plants are rich in myriad metabolites (phytocompounds), due to their immense potency towards, vital industrial products, food, feed, and medicines. The commercial natural products is based on direct extraction from plants or their natural intermediates [3]. The alarms are ringing aloud about their extinction due to overexploitation accounting for two tens of a hundred, of which 30% have medicinal value [4-5]. Due to such lacunas, while cultivation, plants with long growth cycles still lower yields, and conventional extraction cannot meet the huge demand at hand (Increased population and decreased land resources and seasonal variations due to global warming). Thus, alternative measures for the cultivation of plants as sustainable measures are a requisite for their metabolites of prime importance [6]. Biotechnologists have devised engineering solutions by engineering these metabolic processes for the desired production of these metabolites [7]. The direction of the flux is very important with yield enhancement and focusing on the intermediates leading to directionality.

One such culture condition on a lab scale has been adopted way back which preserves the plant independent of the seasonal stresses and leading to plant maintenance, known as plant tissue culture. The explants for generation could be cells, organ, tissue specific under sterile conditions. The technique (Fig.1) covers a wide range of purpose from developmental process of the plant to study of gene at functional level, crop improvement and plant breeding, generating virus free, healthy plant material and its conservation, transgenic plants development with specific agronomical and industrial traits, rescue of endangered plant species [8].

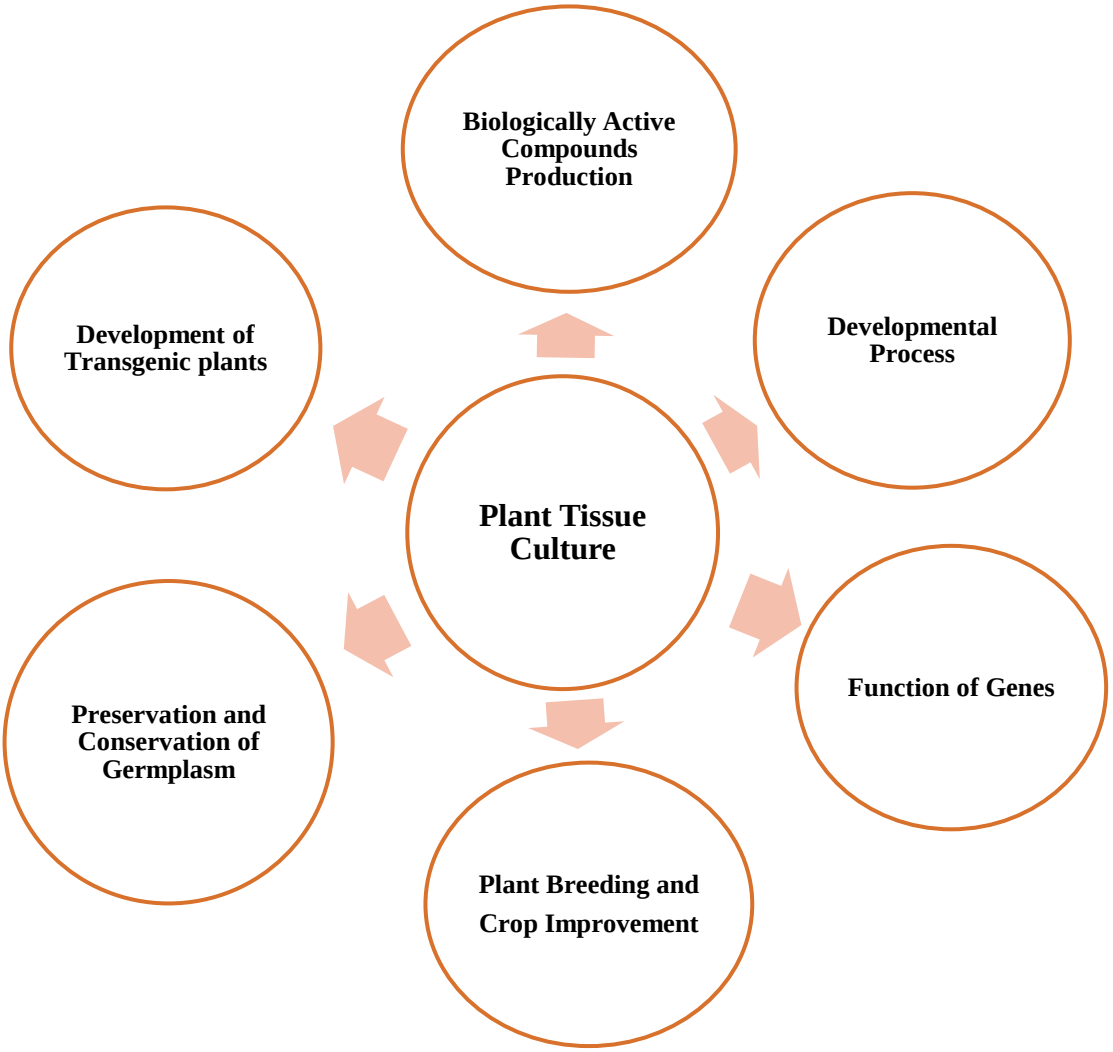

Fig.1 Importance of Plant Tissue Culture

Limitations of Plant tissue culture

The technique of micropropagation isn't limitless, it faces challenges due to media composition, rich in complex sugars, requiring aseptic maintenance, increasing the cost burden and scale-up of plant cultivation cannot be ascertained. The cell death due to browning, cross-culture contamination, and sometimes environmental conditions such as low light intensity, hormonal imbalances, and oxidative stresses caused by high salt uptake leads to hyper hybridity which results in physiological malformation [9]. The method has been updated with cost-effective soil-less cultivation techniques (Hydroponics/aeroponics) which were used for ornamental plants in ancient Greece [10].

Hydroponics

Hydroponics is a technique of soil-less cultivation of plants, devised by Gerick, Hoagland, and Arnon. The technique has been a success-driven approach, by enhancing the yield, biomass, and

foliage. The intensive setup involves greenhouse maintenance with smart farming approaches, and vertical farming setups, paving the way for the future of sustainable agricultural solutions. The requisite companions can be rockwool, clay pebbles, vermiculite, cocopeat, and others. Factors such as that of availability of a large space, suitable growing media, expected productivity, and quality of the product such as free from pesticides, shape, and others play important roles in selecting the technique [11]. The controlled environment consists of temperature, light intensity, irrigation frequency, whether in batch mode or changing nutrient media, and humidity [12]. The goal shifting from conventional food crops grown in hydroponics to medicinal plants, one such study by Maneeply et. al, 2018 with Brahmi (*Bacopa monnieri*) known for its nootropic value, and updated by Aggarwal and Mathur, 2020 with variable light intensities and commercial media vis a vis MS media reported for the effect on bacoside (secondary metabolite governed by MVA pathway) content [13]. The medicines with their exorbitant prices and high demand owing to the increasing burden of diseases demand plant production at a greater scale. The goal is clear to cultivate plants with unparalleled and excellent quality and with high proportion of valued bioactive substance [14].Studies have reported that use of hydroponic technique for acclimatization of *in vitro* cultured plants have improved growth and survival rate in hydroponically grown plantlets when compared to their conventionally grown controls [15].Various types of plants from crops, vegetables, fruits, condiments to medicinal plants have been propagated using Hydroponic technique such as cereals, fodder, fruits ,vegetables, spices, and medicinal plants (Aloe vera) [16]. Table 1 depicts some success stories of recent decade in terms of hydroponics.

Table.1 Some fruiting and medicinal plants with enhanced bioactive substances when cultivated in hydroponics

Plant Species	Secondary Metabolite	Yield or Percentage increase	References
Strawberries (*Fragaria × ananassa*)	ascorbic acid tocopherol Polyphenolic compounds	74 % 53 % 22%	[17]
Raspberries (*Rubus idaeus*)	ascorbic acid Polyphenolic compounds	83 % 67 %	[17]
Chrysanthemum	Flavonoid Chlorogenic acid	Higher yield	[18]
Achillea millefolium	Flavonoids	(0.43% w/w dw)	[19]
Mentha spicata L)	Volatile oil	High production	[20]

Effect of certain abiotic factors on metabolomic profile of plants

Studies (eco-metabolomic researches) conducted *in situ*, the acquiring environmental stresses, temperature, seasons, topography, toxic chemicals, pathogens, soil conditions, salinity, pH [21] heavy metals, excess nitrogen and carbon dioxide [22-23] depicts changes as the impact of

environmental conditions on metabolic reactions occurring within the plants. Such stresses are regulated using suitable cultivation conditions as discussed in the above paragraphs.

Factors affecting metabolic profile of plants when grown in Hydroponic conditions

Furthermore, studies depict a wholesome picture of how plants are thriving in alternate cultivation conditions and the factors that are responsible for their survival and growth. Some of them are discussed as follows:

Salinity of the nutrient medium

Tanaka et al., 2000 recently showed that in a tropical mangrove, *Bruguiera sexangula*, resistant to salinity gradients, the sodium as an antiporter catalyzes the exchange of sodium for hydrogen through vacuoles [24]. Seedlings of *B. parviflora*, different NaCl concentrations were used, the overall levels of chlorophyll and carotenoid pigments altered with changing chlorophyll content could be attributed to the chloroplast damage or alteration in the pigment-protein complexes, and spike in chlorophyllase response [25]. The changes were also seen in phenolic content and protein levels. Studies report the similar changes in various plants [26-27]. Another plant of study *Salvia miltiorrhiza L*. had been studied for its growth and metabolic responses. A plant of medicinal worth was studied while propagation assisted with varying salinity and resultant changes in concentration of ions, osmotic potential and antioxidant activity. There were changes in chlorophyll-b content in response to NaCl variation and a decrease in potassium and calcium content. The antioxidant potential was compared with SOD and CAT activity. Also, soluble sugars, and proteins enhanced considerably with hypertonicity [28].

pH

The lab setup of plants; *Rhodendron* plants grown in suitable pH solutions showed no root morphological alterations. Plants growing in high pH solutions, on the other hand, formed small, highly branching primary and secondary roots that grouped in the lower part of older rootlets. Plants grown at a lower pH (5.5) than (6.5) gave observations with higher dry weight of leaves and larger surface area of leaves. The concentrations of macro and micronutrients in roots and leaves were altered by pH. absorption of nutrients by roots in high pH solutions resulted in lower concentrations of Nitrogen, Sulphur, Copper, and Zinc and higher concentrations of iron complexes with Boron than plants grown in optimal pH conditions. On the other hand, P, Mg, S, Mn, and B concentrations were lower in leaves grown in high pH conditions [29].

Concentration of macro and micronutrients and light intensity

Nitrogen assimilation by plants happens in the form of nitrates and is significant for plant processes [30-35]. The majority of amino acids were found to decrease gradually in plants growing under intense light conditions as nitrogen deficiency is progressed. One such experiment with, tomato plants with low light and nitrogen resulted in fascinating observations. The amino acid content declined, chiefly of alanine, arginine, aspartate, and glutamate, much reversed for high-intensity light conditions. However, there are major changes in reaction between the two

tests. Levels of serine, b-alanine, and GABA (significant in the case of serine) increased towards the end of this trial. The nutrient variation was seen in the content of sucrose, hexoses and starch stored in the leaves of *N. plumbaginifolia* that was grown in CO_2 enriched environment, no visible change was seen in the foliar carbohydrate that got collected in hydroponically-grown plants at high CO_2 concentrations [36]. Another study with basil plants in the appended nutrient mixes resulted in a positive correlation with growth and biomass. The compounds altered with different nutrients interplay were phytocompounds like, alkaloids, several flavonoids, and terpenoids and arginine spike in leaf region [37]. The other medicinal plant studied for its growth characteristics and metabolic profile. The biomass increased with the picrosides seen for plants cultivated under aeroponic condition [38]. Many tea cultivators being science enthusiasts study effect of light spectrum, One such study with all around UV-B resulted in change in tea quality by shifting the flux towards flavonoid biosynthesis. In this very recent study, the farm was experimented for, presence of UV-B and absence of flavanol based glycosides (kaempferol-7-O-glucoside, myricetin-3-O-glucoside, and quercetin-7-O-glucoside) but enhanced catechins [39]. Nutrient omission in the plant *Melissa officinalis* led to changes in growth, content and composition in the essential oil [40].

Conclusion and future challenges

The current review focuses chiefly on how plant metabolism is affected and regulated by the interplay of environmental cues like water, light, and carbon-nitrogen (for amino acid synthesis and resulting in flux towards nucleotide synthesis). The intriguing question remains unanswered how the plant prioritizes its metabolic responses. While encountering different biotic and abiotic stresses, the nutrients in deficit and excess amounts play different roles. The major tenets attributed to the following research avenues are as follows:

1. Identification of functional parameters and resultant stimuli (E.g. Different nutrients and light intensities playing a role in the synthesis of secondary metabolite).
2. The parameter of time and studies in correlation.
3. The increase in spatial resolution for assessing changes in different plant parts based on changes in phytohormones based on flux shifts (E.g. plant root elongation, lateral roots development, internodal length, number and size of leaves, thickness of stem).
4. Obtain information, integrated based on unique model development and prediction of metabolic profiles of plants; medicinal importance.
5. Smart technology for studying the switch point of these fluxes to understand crucial steps of these metabolic processes.
6. Last but not least, metabolomics researches have to be integrated with plant hormone production to better assess the stresses and related primary pathways switching to secondary pathways.

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