ANALYSIS OF ENVIRONMENTAL AND GROWING CONDITIONS FOR MAXIMUM YIELD OF CHICKPEAS CULTIVATION IN VERTICAL HYDROPONIC SYSTEMS

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Abstract

The global demand for plant-based protein sources increases analogous to the increase of the world population. This conventionally requests the need for more agricultural land, which is unfortunately becoming scarce due to many reasons. Therefore, the interest in innovative and promising farming methods (vertical farming, aquaponic, urban farming, hydroponics, etc.) increased immensely in the last years. The fully automated vertical hydroponics technology is one of the promising soilless culture systems that provides more yield per unit area. However, accurate knowledge about plant requirements at different growth stages are necessary to realize the optimal growing condition within the hydroponic systems and consequently to obtain the highest possible yield and quality of the crop. Chickpeas is one of the most important plant-based protein sources and it has high nutritional value and plays a central role in various diets. However, chickpeas have not been the focus of hydroponics cultivation so far, there are few studies in this field. This paper provides a detailed review about the relevant researches about chickpeas cultivation, to study and analyze the growth parameters needed for the design of appropriate vertical hydroponic systems. In other words, all required parameters (light, temperature, moisture, essential nutrients, etc.) to be controlled are defined and analyzed. Suggestions and recommendations for initial studies and prototypes are generated.

Keywords: *Hydroponics, vertical farming, soilless culture, plant-based protein, chickpeas, aeroponics*

1. INTRODUCTION

The continuous increase in the world's population, climatic changes and the accompanying water scarcity, the accelerating shortage of agricultural land, as well as the increasing demand for plant-based protein sources, require the development and realization of efficient and innovative agricultural techniques to increase agricultural yield to meet human food needs in general and plant proteins in particular. Vertical farming and hydroponic techniques represent some of the most cutting-edge advancements in agriculture over the past several years. Thanks to remarkable progress in these methods and their associated system components, they have found extensive application not only in small-scale cultivation projects but also in large-scale mass agriculture production.

Cultivating crops within closed hydroponic systems offers numerous advantages. These benefits encompass (Despommier, 2020):

- Minimizing detrimental environmental impacts linked to outdoor farming, such as over-fertilization, soil pollution from fertilizers, and excessive pesticide use.
- Enabling year-round cultivation, breaking free from seasonal limitations.
- Drastically reducing water usage by up to 95% compared to conventional farming methods.
- Augmenting agricultural yield by mitigating the impact of diseases that often hamper productivity.
- Leveraging vertical farming techniques to further enhance productivity and space utilization.

Furthermore, hydroponic systems can be established in regions, where conventional cultivation of specific plants is unfeasible due to challenging climatic conditions or infrastructure limitations.

Within hydroponic vertical farm systems, crops are grown in place-efficient stacked form. Thus, little space is needed and plants could be centrally grown within the constantly growing urban areas (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung, 2023). This proximity could lead to a reduction in pollutants caused by transport routes.

The present work focuses on the cultivation of chickpeas (Cicer arietinum L.) within vertical hydroponics farm systems. Chickpeas, as a legume, have a particularly high plant protein content. In addition, plant protein sources offer a cost-effective and resource-efficient alternative to animal protein sources (Ismail et al., 2020). The primary cultivation regions of chickpeas are mainly concentrated in the Far East, including countries like India, Pakistan, and Burma. Additionally, they are cultivated in the Mediterranean region, encompassing countries such as Turkey, Syria, North Africa, and Spain. (Bayerische Landesanstalt für Landwirtschaft). The global production of chickpeas in the past ten years has been fluctuated between about 11 and about 17 metric million tons as it is introduced in (FAO, 2023) (Fig. **1**). This fluctuation is primarily attributed to the challenges posed by climate change. Climate change has emerged as a significant obstacle in chickpea cultivation, impacting production and productivity. Adverse consequences of climate change, including drought, high and low temperatures, and excessive moisture, have been affecting crop yields in various regions worldwide. On The other hand, the proportion of chickpeas consumers is increased in the last years (Rehm et al., 2023). The scarce supply meets the increasing demand and results in increased economic burdens.

The chickpea is not native to German latitudes. The climatic conditions in the countries of origin and main cultivation areas differ significantly from those in Germany. In addition, legumes, such as chickpeas, are expected to play a significant role in the German and European strategy for growing protein-rich plants for the production of meat substitutes and animal feed. Reducing imports from main cultivation areas is also expected to have a positive impact on climate protection. Furthermore, the aim is to reduce the consumption of mineral nitrogen fertilizers and improve soil fertility. For this purpose, the German government and the EU provide funding for farmers and researchers (BMEL, 2022). As a result, there is a growing interest in further researching the cultivation of chickpeas, regarding optimum growing conditions within weather-independent vertical farming systems, in order to cultivate it in non-native regions.

Through a comprehensive literature review, it has been observed that chickpeas have been cultivated hydroponically to investigate abiotic stress factors (Alloush, 2003; Bahavar et al., 2009; Imtiaz et al., 2017; Peter Downing/Media Production). However, the optimization of growing conditions for chickpeas in hydroponic vertical farm systems remains relatively unexplored due to its current lack of economic relevance.

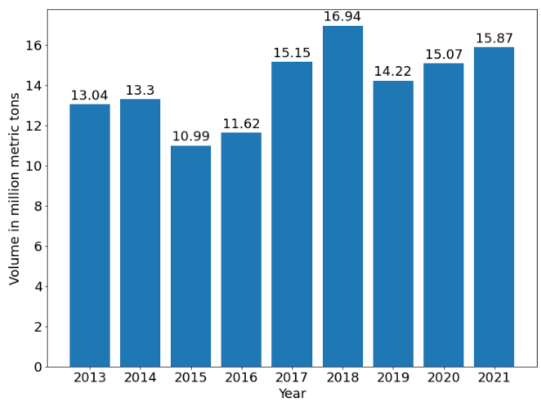

Fig. 1. Chickpea yield worldwide

2. THE JOURNEY OF CHICKPEAS: ORIGINS, SPREAD, GENOTYPES AND GROWTH

2.1. Origins and global spread

The cultivated Chickpea, Cicer arietinum L., most likely originated in the area of today's southeastern Turkey and adjacent Syrian areas (K.B. Singh, 1997; van der Maesen, 1972). The earliest records of chickpeas used as food are dated to 7500 - 6800 BC. Evidence of the earliest cultivation of Cicer arietinum, as well as the wild progenitor Cicer reticulatum, was found at Tell el-Kerkh, Syria (R.J. Redden, J.D Berger). The cultivation of the chickpea spread from Syria to Europe and Western and Central Asia around 5500 BC. It became accessible to the New World through the Spanish and Portuguese by 1500 AD. Around 1800 AD, the chickpea reached India via the Silk Road (R.J. Redden, J.D Berger). Moreover, linguistic evidence shows that the chickpea spread to India via Kabul (which was on the Silkroad) and thus received the name *Kabuli chana* (chana: chickpea) in Hindi (K.B. Singh, 1997). Today's most consumed chickpeas within the Middle West are the cultivated Kabuli genotype.

2.2. Chickpeas genotypes

In general, there are two superior types of chickpeas, the Kabuli type and the Desi Type (R.J. Redden, J.D Berger, p. 5). The Kabuli type is most common in western Europe and it is particularly used for popular dishes like Hummus and Falafel (Daba et al., 2016; Reuber and Rückert). Numerous genotypes of both superior types have been bred to make the plant as productive as possible and to adapt it to environmental conditions. The Genotype-Environment Interaction (GxE) was employed in many research studies to assess the yield stability of different genotypes across various environments (Arshad et al., 2003; Dhuria and Babbar, 2019; Qureshi et al., 2015).

Since in hydroponic system plants are not exposed to any abiotic stress, there is no need to consider soil drought on yield. The best genotype to use in hydroponic cultivation systems in Europe should have maximum yield, short cultivation time and does not need high ambient temperature.

Many publications do not specify the superior type of chickpeas, nonetheless it is found in (Zaman-Allah et al., 2011) that sensitive, not-drought-adapted genotypes had a higher yield under well-watered conditions than drought-adopted genotypes. In (Dhuria and Babbar, 2019), the JGK12 Kabuli genotype was the highest in yield with an expected value of 59.8 pods per plant and one of the shortest in days to maturity with an expected value of 97 days. Due to the high yield and the short maturation period, this genotype will be further investigated in the future hydroponic system.

2.3. Growth stages

To implement a hydroponic vertical cultivation system for chickpeas, the growth stages of the plants must be analyzed. In Canada, the average maturity of chickpeas ranges from 91 to 136 days after sowing (DAS) (Gan et al., 2009).

As it is introduced in (Grains Research and Development Corporation, 2018), chickpeas have two distinct growth stages, the vegetative and reproductive phases (Fig. ***2***). The vegetative phases are definite by counting the number of developed nodes above the ground, and the reproductive phases start with the first flowering node. The plant reaches a growth height between 40 and 60 cm. For better classification, the growth stages are marked with the letters and numbers. The letter "V" stands for vegetative and "R" for reproductive phase. The first vegetative growth stage is germination (VG) and the sprouting of the primary roots followed by the seeding emergence (VE). Fully expanded leaves at the first node describe the next stage (V1). The second multifoliolate leaves to the second node are unfolded (V2). The main yield comes from the branches of the first three nodes (V3). A node is valid when the leaves are unfolded and flat (Vn). The plant begins flowering at the first reproductive growth stage (R1) and developed a flower bud. Sepals begin to form at the calyx opening (R2). During the anthesis (R3) pollination happens. The bud opens to a flower (R4), the Kabuli type forms white flowers. After that, the flower collapses (R5). The pod growth starts (R6) and develops into a mature pod (R7). Seeding begins in the fully expanded pod (R8) and fills the cavity of the pod (R9). Maturity begins (R10) by turning the pod into a light golden yellow color. In stage R11, chickpeas are about 50% mature and they achieve a maturity of 90% in stage R12. As chickpeas are native to dry climatic conditions, they develop a strong and deep root system with a taproot (Grains Research and Development Corporation, 2018).

The investigations of (Eker et al., 2022) showed a plant height of 52.3 cm for Kabuli type chickpea. Among them, the height of the first pod was 31.3 cm and the width of the canopy was 49 cm. According to the studies of (Dotaniya et al., 2022), the height after the first 30 DAS was 15.6 cm (VG-V3), after 60 DAS 41.5 cm (R1-R4) and after 90 DAS 64.4 cm (R5-12).

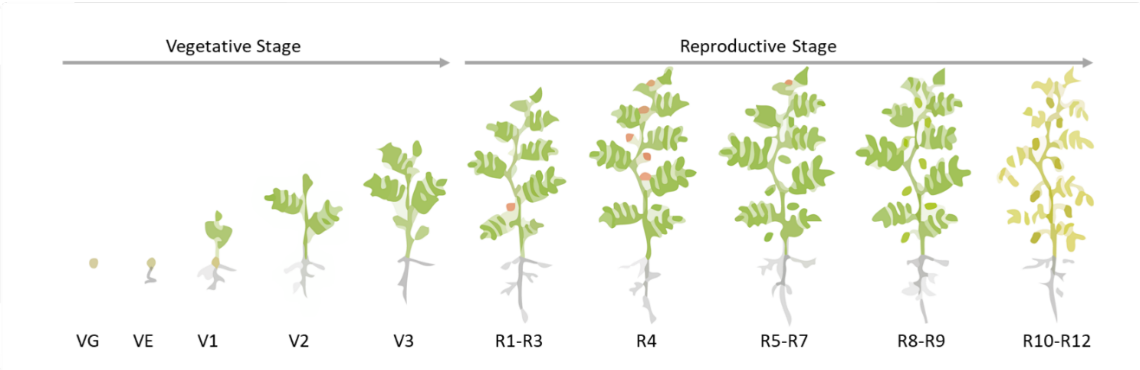

Fig. 2. Growth stages of chickpeas
Source: basically adopted from adobe.com/ ilyakalinin

3. GROWTH PARAMETERS

To optimize yield, taste, and nutritional value in a hydroponic system, the creation of optimal conditions for plant growth is necessary. Hydroponics allows precise control over crucial environmental factors such as, nutrient concentrations, pH levels, temperature, humidity, and light, enabling fine-tuning and customization to meet all plant requirements for optimal growth. This level of control enhances the potential for achieving superior crop performance and desired quality attributes in hydroponic cultivation.

3.1. Light

Plant growth is significantly influenced by light through three essential mechanisms: photosynthesis, photomorphogenesis, and photoperiodism. Photosynthesis is a fundamental process, in which plants utilize light energy to convert carbon dioxide and water into glucose and oxygen. As the primary energy source, light drives crucial biochemical reactions that facilitate the synthesis of carbohydrates, sustaining plant growth and development. Photomorphogenesis describes how light impacts plant morphology and development. Various wavelengths and intensities of light play critical roles in regulating specific aspects of plant growth, including stem elongation, leaf expansion, and branching architecture. photoperiodism is a crucial physiological response exhibited by plants in relation to the duration of light and darkness they experience within a 24-hour period. Photoperiodism regulates the timing of flowering and other reproductive processes in various plant species, enabling them to adapt and synchronize their life cycle with seasonal changes and environmental conditions. To facilitate optimal plant growth, the plant needs enough usable light. For plants, this is measured in photosynthetically active radiation PAR, which describes a specific range of electromagnetic radiation wavelengths (usually between 400 to 700 nanometers) that plants can absorb and use for photosynthesis. Since no definitive studies have been conducted yet, for a first indication, the PPFD parameter 300 and 600 µmol/sm² from the studies (Kumar et al., 2020; Shrestha et al., 2019) are used.

In (Grains Research and Development Corporation, 2018), chickpea is described as a photoperiod-sensitive and long-day plant. In addition, flowering is negatively affected when the photoperiod falls below 17 hours. Similar conclusions are reached in (Daba et al., 2016; Roberts et al., 1985) which observed earlier flowering when the photoperiod duration was 15 h compared to 12 h. Additionally, (Daba et al., 2016) also observed an earlier occurrence of flowering at 16 hours compared to 10 hours.

3.2. Climate

3.2.1. Carbon dioxide (CO2)

CO2 is a vital raw material for photosynthesis and plays a crucial role in various physiological processes linked to plant growth. As CO2 concentration increases, essential factors like photosynthetic rate, plant dry weight, soluble sugar, and chlorophyll content show improvement (Ahmed et al., 2020). CO2 enrichment in greenhouses has also been shown to enhance plant growth and overall productivity. Commercial greenhouse operators have reported significant benefits, such as a 20%-30% increase in tomato yields, up to 40% increase in cucumber yields in Ohio, and a 20%-30% rise in lettuce yields per crop (Resh, 2013). (Resh, 2013) concluded that maintaining an optimal CO2 concentration is vital for maximizing profits in greenhouse cultivation. Additionally, the ideal CO2 level depends on factors such as crop growth stage, species, greenhouse location, time of year, and type. In general, optimal CO2 levels range from two to five times normal atmospheric levels, approximately 1,000-1,500 ppm CO2. Furthermore, with CO_2 enrichment, one can anticipate increased fertilizer and water demands as plants tend to grow more vigorously. Additionally, it is important to know that increasing CO_2 concentration increases the optimal temperatures for plant growth (Chukwunalu et al., 2020; Ying Zhang and Murat Kacira).

Since there is a lack of research on chickpeas in controlled cultivation systems, starting with an initial concentration of 800 ppm and changing the concentration in future cycles depending on the results are recommended.

3.2.2. Vapor Pressure Deficit (VPD)

Vapor Pressure Deficit (VPD) measures the difference between the amount of moisture in the air and its maximum holding capacity at a specific temperature. It indicates the air's drying power and helps understand plant water loss through transpiration. It can be calculated based on the relative humidity (RH) and the temperature (1) (Peter Kuverda, 2020). Temperature affects the ability of air to hold water (Lawrence, 2005) and therefore influences the saturation pressure (p_{sat}) which is used to calculate the VPD:

$$VPD = p_{\mathrm{sat}}(T) * (1 - \frac{RH}{100}) \qquad (1)$$

Transpiration is the release of water vapor through stomata in plant leaves, facilitating osmosis, nutrient supply, evaporative cooling, and entry of CO_2 (Sadava et al., 2019, pp. 1062–1064). The ability of a plant to evaporate water through its stomata is known as stomatal conductivity. It is affected by the ambient humidity, the ambient and plant temperature, light conditions and wind or air circulation (Tracy M. Sterling, 2023). Transpiration and VPD thus influence each other reciprocally (Elly Neferhoff, 2009). A high transpiration rate (TR) can lead to a decline in growth quality. Low TR lead to a nutrient undersupply since no osmosis takes place (Tracy M. Sterling, 2023). The water vapor conductivity of the leaf boundary layer can limit transpiration. To ensure that the water vapor conductivity of the boundary layer is higher than that of the stomata, sufficient ventilation is required (Matyssek and Herppich, 2019). Therefore, a current air speed of 0.5-1.0 m/s is recommended (Genhua et al., 2020). The slope of TR with increasing VPD differs among different chickpea genotypes as shown in (Sivasakthi et al., 2017). Similar was found in (Sivasakthi et al., 2020), where 4 different genotypes showed 4 different behaviors of the TR in respond of increasing VPD. It should be considered that the optimal VPD values can vary during different growth phases of a plant. Typically, plants tend to favor higher VPD values during the vegetative phase, whereas they prefer lower values during the flowering and fruiting phase. It is crucial to adapt and fine-tune the VPD levels according to the specific developmental stage of your plants (Elena, 2023).

Since there is lack of research about the optimum VPD for chickpeas, an initial VPD of 0.95 kPa (in VG) / 0.85 kPa (in R) is recommend the suggested VPD for most crops (Genhua et al., 2020; Na Lu).

3.2.3. Ambient temperature

The temperature also influences plants metabolism since they are ectotherm (CANNA Research, 2023). The optimal temperature range varies by genotype and depends on plant life stage since temperature can initiate phases (Devasirvatham et al.). In (Clarke and Siddique, 2004), it was found that the minimum temperature needed for germination (VG) seems to be 7 °C. In (Croser et al., 2003), 10-25°C is the suggested temperature range during vegetative phases (VP). high temperatures (>35 °C) initiate early flowering and reduce crop growth (Devasirvatham et al.) in reproductive development (R). In (Clarke and Siddique, 2004), it was found that the threshold for the Kabuli genotype was 15°C, with no increase in pollen tube length at higher temperatures. Studies on heat stress in chickpea genotypes show that temperatures above 30 °C lead to loss of flower buds (Devasirvatham and Tan, 2018; Grains Research and Development Corporation, 2018). Even if vegetative or reproductive growth is possible within the described temperature ranges, a temperature from 20°C in the VP to >20°C in the RP is recommended across genotypes (Devasirvatham et al.; Rani et al., 2019). Therefore, the temperature in the hydroponic system has to be between 20 °C and 25 °C depending on the plant life stage and the used genotype. At night the temperature should be lowered to ensure optimal growth (van der Zanden, 2008).

It is important to consider that all these parameters including light conditions influence each other mutually, which is why the final adjustment must take place in the specific application and environment.

3.3. Water

Water is a key factor for the improving crop production, as it affects all physiological processes of plants. The water consumption of plants is defined by the total evaporation of the atmosphere that prevails during the growing season of the plants (Sekhon and Singh, 2007). Evapotranspiration is composed of direct evaporation from land surfaces and transpiration caused by plants (Irmak and Haman, 2003).

Various studies have been conducted to determine the water consumption of chickpea, which shows the importance of irrigation for increasing yields (SINGH et al., 2016). Under full irrigation, water consumption ranges from 175 to 426 l/m^2 depending on the growth stage (Anwar et al., 1999). The water consumption of type desi ranges from 28.8 to 37.4 liters per plant (Pang et al., 2017). The findings suggest the water consumption of chickpeas under field conditions, yet the precise amount required for a hydroponic system necessitates additional research. The water temperature affects metabolic activities of plants and can lead to improvements under optimal conditions. It depends mainly on the stage of growth and the type of plant (Nxawe et al., 2011). Water temperature affects nutrient and water absorption in hydroponic systems, as well as fertilizer solubility and plant oxygen consumption (Libia I. Trejo-Téllez and Fernando C. Gómez-Merino, 2012).

(Resh, 2013, p. 95) suggests keeping nutrient solution temperature in the range 15.5-18 °C. In the study conducted by (Thakulla et al., 2021), it was observed that lettuce growth experienced a notable increase at 21.1 °C compared to 18.3 °C.

Based on the literature research, a consensus among experts is observed regarding the lower limit of the optimal water temperature range, which is around 18 °C. However, there are varying opinions and disagreements concerning the upper limit. According to the literature research, the upper limit of the optimal water temperature range falls within the range of 22 °C to 27 °C (Azhari et al., 2022; Bugbee, 2004; David, 2022; Nimje and Handa, 2023).

For the initial implementation phase, which involves the hydroponic cultivation of chickpeas, it is advisable to maintain the water temperature within the range 18-22 °C. This range falls within the commonly agreed-upon optimal temperature limits and is expected to support favorable conditions for the growth and development of the chickpeas.

Dissolved Oxygen (DO) prevents waterlogging and must be added in hydroponic systems (Mattson and Lieth, 2019). Temperature fluctuations affect the DO in the water and the oxygen consumption of the roots. Rising temperature increases the oxygen demand of the roots and decreases the dissolved oxygen (J. Graves, 1983). Studies show that increasing DO from 7 to 23 mg/l improves lettuce growth (Suyantohadi et al., 2010), but increasing DO concentration has no effect on lettuce yield, according to (Goto et al., 1996). Due to the absence of precise data on chickpeas, the established values are provided as initial guidelines and require further determination. The suggested range for the system is between 7 and 10 mg/l.

3.4. Nutrients

Maintaining balanced nutrition is of utmost importance in hydroponic plants cultivation to prevent plant diseases and ensure optimal yield (Toker et al., 2007; van Gastel et al., 2007). Seventeen essential elements that significantly contribute to plant growth include N, P, K, Ca, Mg, S, Fe, Cu, Zn, Mn, Mo, B, Cl, Ni, C, H, and O (Rochimi Setiawati et al., 2019). Inorganic nutrient solutions are commonly used in hydroponics because organic molecules, among other disadvantages, do not conduct electricity, making EC measurement inaccurate (Williams and Nelson, 2016). Results of the research of (Ahmed et al., 2021) showed that plants grown with inorganic nutrient solution had better growth than those grown with organic solution.

The four standard nutrient solutions suitable for growing most plants are the Hoagland, Hewitt- or Long Ashton, Cooper- and Steiner solution. Even though these solutions are basically suitable for many plant species, they are not specifically adapted to certain plants and growing conditions (Ali Al Meselmani, 2022).

Given the limited available data for chickpeas and the variations in nutrient requirements among different genotypes, it is essential to regularly adjust the optimal nutrient solution based on plant measurements and disease patterns. By monitoring the plant's development and response, the nutrient solution can be fine-tuned to ensure the best possible growth and health of the chickpeas over time. The initial nutrient solution for hydroponic growth of Kabuli chickpeas can be taken from (Alloush, 2003) and is shown in Table 1.

Table 1. Recommended initial nutrient solution based on (Alloush, 2003; Hewitt, 1966)

Salt	Concentration [mg/L]	Salt	Concentration [mg/L]
$Ca(NO_3)_2$	246	$MnSO_4 \cdot 4H_2O$	2.24
KH_2PO_4	136	Fe-Citrate$\cdot 3H_2O$	5.09
$MgSO_4$	60	H_3BO_3	3.1
$ZnSO_4 \cdot 7H_2O$	0.29	$Na_2Mo_4 \cdot 2H_2O$	0.121
$CuSO_4 \cdot 5H_2O$	0.25		

The pH levels in nutrient solutions are critical for plant growth, with nutrients only soluble at specific pH levels (Ali Al Meselmani, 2022). If the pH is on the wrong level, deficiency symptoms can occur. A pH range 5.5-6.5 is suitable for most plants (Ali Al Meselmani, 2022), but for hydroponically grown chickpeas, a range of 6.0 (Alloush, 2003) to 6.5 (Amalraj et al., 2019) is recommended.

The electrical conductivity (EC) represents the concentration of dissolved salts (ions) in the nutrient solution (Ali Al Meselmani, 2022). Typically, electrical conductivity is in the range 1.5-2.5 dS/m, but this strongly varies between different crops. Furthermore, the EC-value depends on the growth stage of the plant. During growth, the optimum EC-value usually increases. If the EC-value is too high, the absorption of nutrients will decrease due to osmotic pressure, while low EC-value leads to plant diseases and yield reduction (Sharma et al., 2018).

The optimal EC-values for hydroponic cultivation of chickpeas have not been definitively established; however, a suggested typical range of 1.5 to 2.5 dS/m is recommended. As further research progresses, adjustments to these values may be identified to potentially enhance the yield of chickpea crops.

4. HYDROPONICS SYSTEMS

4.1. Common types of hydroponic systems

There are passive and active systems for hydroponic cultivation (Table 2). They differ in structure, complexity and efficiency. Passive systems are simple, as they usually do not require electricity, pumps or other means. Active systems are more complex in design, require electricity, but are much more effective.

4.1.1. Wick system

It is passive system (Fig. ***3***). Therefore, a water pump is not required for the transport of nutrient solution. By using fibrous materials that directly contact the roots of the plants, the nutrient solution is transported to the root area through capillary action (Lee and Lee, 2015). Due to its conceptual limitations, the wick system cannot provide sufficient nutrient solution to large plants over a long period of time, making it unsuitable for the cultivation of chickpeas.

4.1.2. Drip systems

Drip systems (Fig. ***4***) are commonly used hydroponic systems, in which a nutrient solution is supplied to plant roots through a dripping irrigation mechanism (Kumar et al., 2021). The solution is transported by a pump through thin hoses placed above the roots. A timer is often used to control the volume of the nutrient solution (Lee and Lee, 2015). The solution drips specifically onto the roots, which can be surrounded by a growing medium or left free-hanging. Excess solution is directed back into the reservoir for reuse (Gaikwad, 2020).

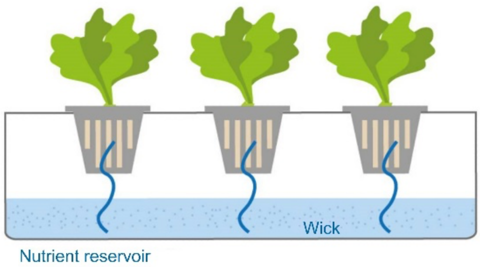

Fig. 3. Wick system

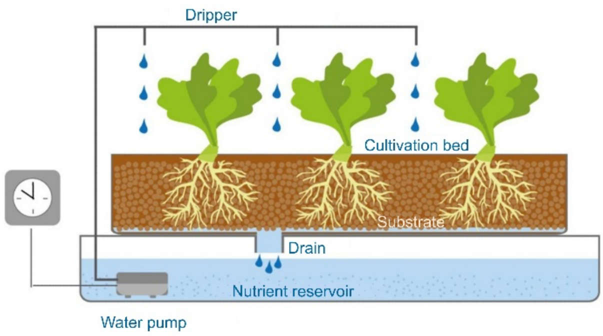

Fig. 4. Drip system

4.1.3. Ebb and flow system

The Ebb and Flow system was one of the first commercially utilized hydroponic systems and a precursor to the widely used NFT system today (Lee and Lee, 2015). The Ebb and Flow system operates by repeating an automated cycle of water and nutrient delivery at regular intervals. During the flood stage, a nutrient solution dissolved in water is pumped from a reservoir into the plant roots, situated in an overlying basin (Halveland, 2020). The roots are flooded with a defined amount of nutrient solution for a set period of time. After the designated nutrient uptake time, the water is then drained out.

4.1.4. DWC system (deep water culture system)

In a DWC system (Fig. ***6***), plants are cultivated on a platform. This platform floats on a nutrient solution dissolved in water (Hamza et al., 2022). The platform is open below the plants being cultivated, such that the roots of the plants are constantly surrounded by water. The nutrient solution is enriched with oxygen by a pump attached to the bottom of the reservoir.

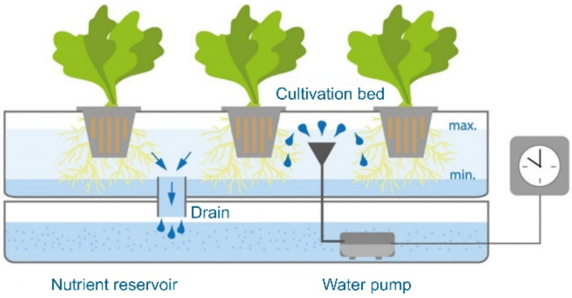

Fig. 5. Ebb and Flow system

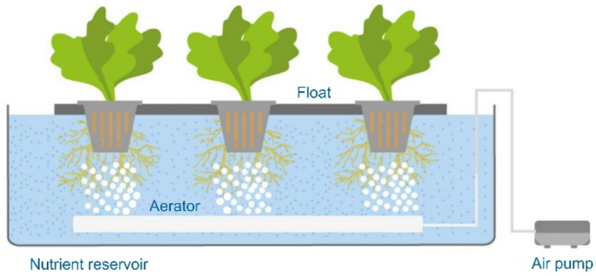

Fig. 6. DWC system

4.1.5. NFT system (nutrient film technique)

The NFT system (Fig. *7*) was developed as a successor to the ebb and flow (Lee and Lee, 2015). Within the NFT system, a nutrient solution dissolved in water circulates throughout the entire system. The roots of the cultivated plants hang or lie in a trough beyond. The mixture enters the trough via a water pump. Through that trough the nutrient solution flows due to a built-in slope and wets the roots (Kumar et al., 2021). A film of water and nutrient solution remains on the roots.

4.1.6. Aeroponic system

Aeroponic systems (Fig. ***8***), classified under soilless farming systems, are advanced and highly efficient greenhouse technologies (Ali Alshrouf, 2017). In aeroponic systems, plants are grown in a closed or semi-closed environment without the use of soil or other growing media. The roots of suspended plants are protected from light exposure, and a nutrient solution is misted onto the roots through pressure nozzles (Li et al., 2018).

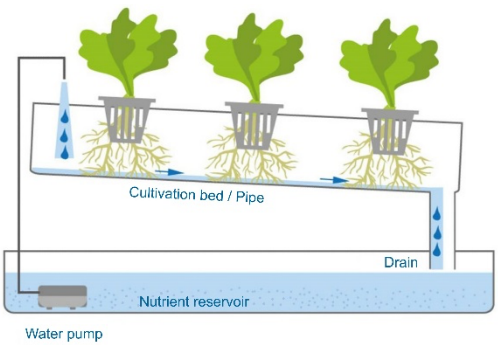

Fig. 7. NFT system

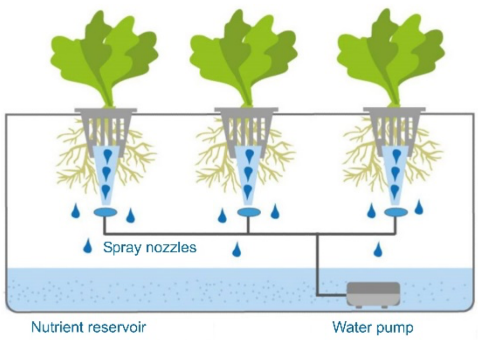

Fig. 8. Aeroponic system

4.2. System recommendation

In Table 2, a brief comparison of the introduced hydroponic systems according to several factors. These factors are:

- Roots: this factor describes whether the system is suitable for short, long, or multiple length of plant roots.
- Complexity: under this factor different systems will be classified according to implementation complexity in large scale.
- Yield: under this factor the factor, the expected yield amount for each system will be denoted.
- Scalability: This factor describes the ability of the system to be implemented in large scales.

- Equality (nutrient solution): this factor describes the ability of the system to ensure uniform distribution of the nutrient amount for all plants in the system.

Based on the literature review and the comparison made above, a hydroponic Drip system with a closed water circuit system is recommended for the hydroponic cultivation of chickpeas. The uniform supply of water, nutrients and oxygen is essential to a research system for optimal growth. Therefore, only Aeroponic or Drip systems are suitable for this application. Drip systems are more cost-effective to construct and less sensitive to system failures than an aeroponic system. The high level of flexibility and ease of use implies that it can also be highly adaptable to unknown root lengths.

Nevertheless, in aeroponic systems, it is possible to maximize crop yields and plant growth by properly setting and continuously monitoring the parameters required for optimal plant growth. Generally, the implementation and operation of an aeroponic system requires a high level of knowledge in biology, plant-specific, and technical expertise and judgment. As the behavior of chickpeas during cultivation within hydroponic systems is not sufficiently researched at present, the use of aeroponic systems is not recommended in the context of the present study. Future research should also focus on determining the root size and water uptake of chickpeas within hydroponic systems to enable the use of aeroponic systems for cultivation of chickpeas.

Table 3 shows the parameters to be regulated. The initial values were derived based on the research from the previous chapters and serve as a guideline for determining optimal parameters for the Kabuli type.

Table 2. Comparison of hydroponic systems

System	Roots	Complexity	Yield	Scalability	Equality (nutrient solution)	Recommendation
Wick	Small plants only	Low	Medium	Poor	Strong	No
Drip	Multiple root lengths possible	Medium	High	Strong	Strong	Yes
Ebb and Flow	Short-medium	Medium	Medium	Medium	Medium	No
DWC	Short-medium	Low	Medium-high	Poor	Poor	No
NFT	Short-medium	Medium	Medium-high	Strong	Medium	No
Aeroponic	Multiple root lengths possible	High	High	Strong	Strong	Yes

Table 3. Proposed target values to control in hydroponic Kabuli chickpea cultivation system

Parameter	Initial target value	Unit
Daytime air temperatures	23	ºC
Nighttime air temperatures	18	ºC
Water Temperatures	20	ºC
pH	6	-
EC	1.5 (VG), 2.5 (R)	dS/m

PPFD, Spectrum	500, 663 (first week)	µmol/sm², nm
PPFD, Spectrum	500, full (until VG)	µmol/sm²
PPFD, Spectrum	1000, full (until R12)	µmol/sm²
DO	10	mg/l
Current air speed	0.5	m/s
CO_2	800	ppm
Humidity (VPD)	0.85 (VG), 0.95(R)	kPa
Photoperiod	17	hours
Composition of nutrients	see Chapter 2, Nutrients	-

5. CONCLUSION AND FUTURE WORK

Since chickpea is one of the important plant protein-based sources and its multiple nutritional uses, and health benefits, the consumption of it is worldwide generally and European particularly significantly increased. However, the European climate conditions are not suitable for chickpea cultivation. For this reason, this paper focused on the analysis the growing conditions of chickpea in order to find out the relevant growing parameters for cultivating it hydroponically. For this purpose, a systematic literature research was conducted, the relevant parameters growth were specified, an initial value recommendation for each parameter was determined. These values were derived based on the given parameter values for traditional cultivation of chickpea (in soil). Therefore, these parameters values have to be tuned and adjusted experimentally and based on machine learning techniques during the experiments of cultivating chickpea in hydroponic simulators.

This paper had briefly addressed the different types of hydroponic systems and analysed them to select the appropriate one for chickpea cultivation. Owing to the performed analysis, drip system seems to be the appropriate system for the chickpeas cultivation.

The next step is the design and implementation of a drip system to cultivate chickpeas. After that, several cultivation experiments should be performed. During these experiments, growth parameters have to be tuned to study their effects on the growth and the yield of chickpeas. Furthermore, with the help of machine learning algorithms and based on the acquired data, regression models have to be developed to assist the prediction of the optimal growth parameter recipe of chickpeas.

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