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# Vegetable production using a simplified hydroponics system inside City of Dead (Cairo)

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**Abstract: This research work was performed in the poorest urban area of Cairo (Egypt) in a slum area called Al-Quarafa. The aim was to develop and evaluate a simplified hydroponics system (HS) to grow vegetables for the local inhabitants who live in an extreme status of food unsafety. In the hydroponic growing system the tomato plants were cultivated and two substrates were compared: peat:perlite (70/30 W/w) and sand:coir (50:50 W/w). This technique guarantees high levels of production and low contamination by avoiding the use of polluted urban soils which are often common in slum areas. Macro and microelements in tomato fruits were analysed by ICP-MS. Results showed low concentrations of heavy metals (Cd, Sr, As, Cr, Mo) with all heavy metals under the levels set by European Community laws. Lack of food safety in slums is more closely linked with malnutrition than starvation, so it is also important to understand mineral availability (both micro and macro) and nutritional significance for health. For this reason micro and macro elements (K, Ca, Na, Fe, Mn, Mg, Cu, Zn) were analysed in the harvested fruits. This study showed that HS is a valid method to grow vegetables in urban areas to improve food security in Middle East cities.**

## 1. Introduction

Food security is a central theme of the new millennium and it must be faced at national and international levels, taking into consideration the multidisciplinary nature of the field which involves socio-cultural, political and environmental, as well as agronomic and economic aspects (Deaton and Paxson, 1998). From an economic and environmental point of view, food security is defined as a situation in which people have safe and appropriate food with nutritional requirements, for an active and healthy life (WFS - Plan of action, 1996). Food security is based on three pillars: food availability, food access, and food uses as reported in the FAO guidelines (Matushke, 2009).

Food security is a priority in all developing countries, in particular in the urban areas of Africa with the Egyptian situation and the conditions of its capital city, Cairo, being critical. Despite the underestimation of risks, the population of the slum areas is affected by malnutrition. In 2005 the Egyptian Demographic and Health Survey stated that 18% of Egyptian youth and 16% of the residents of urban areas were affected by malnutrition. In a city like Cairo, the improvement of agricultural hydroponic systems might be a possible solution to this problem, in particular for informal urban settlements. The development of an efficient and productive growing protocol such as simplified hydroponic systems could be used to grow horticultural produce and increase the availability of natural and safe food for the poorest classes of the population (Dresher, 2004). Food insecurity is a global problem because it is caused by growth of the demand by the world population for secondary food like meat, making, basic resources, such as vegetables and cereals, less available for the poor parts of population (Godfray *et al.*, 2010).

The world's urban population is expected to double in the next 30 years, meaning there will be a growing number of urban poor people. According to the United Nations Human Settlement Programme (UN-HABITAT), urban population expansion will be more pronounced in developing countries as a result

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of high birth rates and immigration from rural areas as people flock to cities in search of food, employment and security. Population growth will lead to an increase in urban slum areas, with high levels of unemployment, lack of food safety, and malnutrition. The increase of urbanization in developing countries enhances food insecurity of large cities. The poorest people move from rural to urban areas in order to improve their life with hopes of finding a job. Unfortunately, in many cases people do not find employment and are obliged to live in the slum areas, increasing the food demand. For this reason, they become more vulnerable in their new position as citizens and consumers. By 2030, it is estimated that approximately 800 million people in developing countries will live in big cities, instead of in rural areas. This prospective is shocking for many nations, in particular for the social and economic relationships among citizens; this phenomenon is unescapable due to economic development and it could create a negative impact on the food security of populations of cities and, in particular, megacities (Cohen and Garrett, 2010) (Fig. 1).

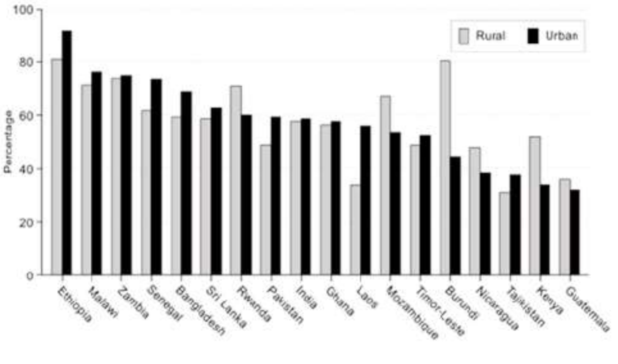

Fig. 1 - Rural and urban index of food energy. International Food Policy Research Institute (IFPRI).

In order to counteract the reduction of food availability in African cities, urban people started growing vegetables in urban and peri-urban areas. Studies showed a considerable degree of self-sufficiency in the production of fresh vegetables, poultry production and the raising of other animals in many large cities of developing countries (Armar-Klemesu, 2000). For example, Dakar produces 60% of its vegetable consumption and produces poultry for 65-70% of the national demand (Mubvami and Mushamba, 2004). Accra produces 90% of the fresh vegetables consumed in the city (Cencosad, 1994; Maxwell *et al.*, 2000). In Dar es Salaam, more than 90% of leafy vegetables in the markets come from the open spaces adjacent to the city or in garden houses (Lee-Smith, 2010). Urban agriculture improves the nutritional state of vulnerable communities as evidenced by studies carried out by Mwangi (1995) in Nairobi. However, one of the main problems of urban agriculture is the competition for spaces within the city itself between people, vehicles, and animals. Another important issue is the agricultural knowledge of the people. Many of them do not know how to grow plants, therefore very simple growing systems must be developed. Simplified hydroponic (SH) systems allow cost-effective agricultural production in confined spaces, such as internal urban spaces, particularly in the cities of developing areas (Seikh, 2006). The SH technique allows higher yield, safer food, and at lower costs. The costs of the entire SH system are fundamental for sustainability of the production of goods; for this reason local materials, best if recycled, were used to construct low budget hydroponic systems.

Horticulture works well in urban and peri-urban zones because it is highly labour-intensive, involving perishable products and short-cycle, productive, high-value crops, which require less land and water per unit of product than other food crops. Hydroponic systems are growing techniques that do not use soil, making them suitable in urban areas to cultivate horticultural commodities (Seikh, 2006). It is a relatively young technique used in commercial fields over the past 40 years (Grewal *et al.*, 2011). The potential of SH is underestimated: it can be a solution for marginal areas, in developing countries with malnutrition problems. SH technique has the objective of reducing the costs of traditional hydroponic techniques, thus making it available and easy to manage for the poor and people without agriculture skills living in slums, like Al-Quarafa.

For the aims of this study, we used local materials to construct SH greenhouses in order to diminish the cost and to make the technique reproducible for the local population. One of the main costs of SH is the substrate, so it is important to understand which substrate is best in which environment. Standardisation of an efficient protocol of SH is important in order to cultivate horticultural products within the urban context (Santos and Ocampo, 2005). Nowadays, many examples of hydroponics are available in developing countries but they are not usually well set up and tend to be expensive. Hence, the new challenge is represented by the inception and enhancement of a hydroponic system sustainable in all aspects, from production to management.

## 2. Materials and Methods

*Simplified hydroponic systems and plant cultivation*

Boxes made of wood (100x50x20 cm) ensure the best conditions for plant growth and for transportation which are fundamental aspects for the socio-environmental context (Iwasa and Roughgarden, 1984). Tomato plants (*Solanum lycopersicum* L.) require a minimum depth of 20-30 cm for root system development (Pardossi *et al.*, 2005). For the present study, plant density was 3 plants/m$^2$. Individual modules of locally manufactured palm wood boxes (50x50x25 cm) were used to reduce the cost of materials, planting one tomato plant per box. The ratio between the surface and the plant was chosen following the standard for tomato crops in open field. All boxes were plastic-coated with a black polyethylene film in order to maintain the moisture of the substrate, preventing excessive evaporation (Hassan-Wassef, 2004). During the summer season, high temperatures in Cairo cause rapid water evaporation, therefore to reduce this affect, the cultivation boxes were covered with white mulching. Evaluation of substrate performance was carried out by comparing the production of 24 tomato plants. For each substrate, plant growth and fruit quality were determined.

*Substrates comparison*

Perlite, peat or coconut fibre, and sand were compared. The substrates were mixed and the final composition was 50% sand + 50% coir (S+C) and 70% peat + 30% perlite (P+P). Three steps followed: fertilization and irrigation up to saturation, mulching and planting, and covering with net-shading to reduce sun intensity.

The fertigation strategy used was based on an initial fertilization with 25 g of 20-20-20 NPK fertilizer containing Fe 5 g/kg, Zn 5 g/kg, and Mg 1 g/kg during the preparation of substrate with the addition of 1 g microelements (Table 1). The peat used had the following characteristics: pH 3.5; EC 10 mS/m; hydric retention 70% vol. Peat pH was adjusted to 5.5 by adding 200 g $CaCO_3$. The simplified weekly fertigation schedule provided irrigation with 20 L/week of water containing 3 g $Ca(NO_3)_2$ for each plant. Nitrogen was provided as 13.7% N-$NO_3$ and 1.5% N-NH4, with a total of 15.2%. The addition of 25 g NPK and 1 g of micronutrients was carried monthly for each box.

Table 1 - EU Heavy metal security limits (EC 420/2011)

| Elements | Concentration |
|---|---|
| Cr | 0.050 mg/kg |
| Pb | 0.100 mg/kg |
| Mo | 0.025 mg/kg |
| As | 3.500 mg/kg |
| Cd | 0.050 mg/kg |

*Assessment of tomato growth and fruit quality*

Plant growth was evaluated monthly and the following parameters were recorded: height, time of flowering, and number of flowers for plants in the different substrate conditions. Fruit quality evaluations were carried out on dried fruits and comprised the determination of macro (K, Na, Ca) and microelements, which are important for a balanced human diet. The concentrations of heavy metals (Cd, Pb, Sr, Cr, Mo, As), as possible contaminants, were also measured. Analytical determinations were carried out using an ICP-MS (Inductivity Coupled Plasma-Mass Spectroscopy). To better understand the potential of the cultivation technique related to the lack of food safety in the slum community, we also analysed the quality of tomatoes bought in local markets of the cemetery area of Al-Quarafa. To evaluate the quality, comparisons were made with standard dried tomato analysed by the FDA (Food and Drug Administration). Dry materials were ground and digested with nitric acid (7:0.1). Mineral compounds (Fe, Mn, Zn, and Cu) were measured using inductively coupled plasma mass spectrometry (ICP-MS). Values were reported as means and standard errors (n=3). Data were subjected to ANOVA analysis and differences among means were determined using Bonferroni's post-test.

## 3. Results

*Plants growth and productivity*

Plant growth was monitored in sand and coir or peat and perlite in the two growth containers during cultivation. Higher values were found in plants grown in the S+C substrate in both palm boxes (Fig. 2A) and woody boxes (Fig. 2B). However, statistical differences were found only in woody boxes. In the S+C substrate the plants reached an average height of 50 cm after three months. In the P+P substrate the plants ranged from 35 to 38 cm. In June, in both substrates, plants reached a plateau (Fig. 2).

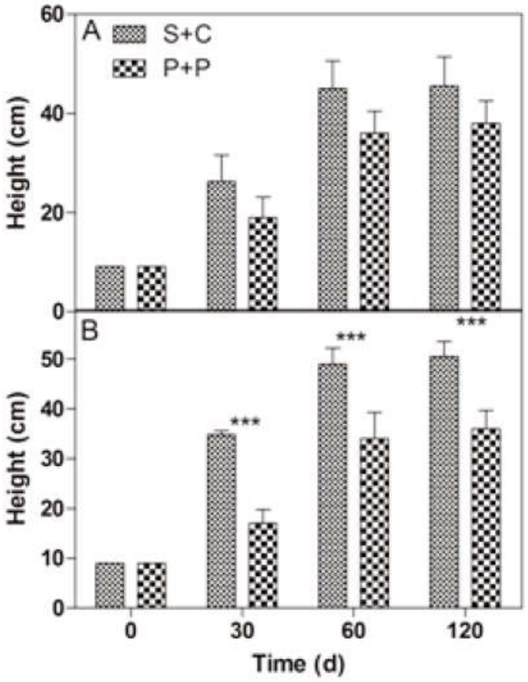

Fig. 2 - Plant height of tomato plants grown in palm boxes (A) or woody boxes (B). Values are means with standard errors. Data were subjected to two-way ANOVA. Differences among means were determined using Bonferroni's post-test.

*Food quality, nutrients and heavy metals content*

The results revealed that simplified hydroponics guarantee the safety of food produced, even in heavy metals-polluted environments. The main mineral nutrient contents were determined in ripe tomato fruits and compared with those sold in the local markets.

The sodium (Na) content was lower in fruits harvested from plants grown in the S+C substrate (1.7 mg/kg DW) compared with the other samples. The fruits purchased from local markets had a higher Na amount: 7.5 mg/kg DW on average (Fig. 3A). The magnesium (Mg) content in fruits grown in SH was similar without significant differences between the two substrates and ranged from 2.7 to 3.4 mg/kg DW (Fig. 3A). In fruits obtained from local markets, the Mg content was almost double (Fig. 3A). Analogous results were observed for potassium (K) and calcium (Ca). The K in fruits harvested from plants grown in the two different substrates ranged from 65.5 to 68.0 mg/kg DW, while for fruits purchased from the markets the values were higher, 110.0 mg/kg DW on average (Fig. 3). The Ca content was similar to Mg, double the content was found in the commercial tomato fruits compared with those harvested from the SH system (Fig. 3A). Considering the heavy metals microelements, different concentrations were found in the tomato fruits. Copper (Cu) in the analysed fruits ranged from 0.6 to 0.8 mg/100 g DW. The highest values were found in the P+P substrate (Fig. 3). Manganese (Mn) was similar in distribution in the different treatments, but the concentration was higher: from 0.7 to 4.4. mg/100 g DW. The highest value was found in the fruits harvested from plants grown in the P+P substrate (Fig. 3). On the contrary, Zn content was higher in the SH cultivated fruits compared with those obtained from local markets. The values ranged from 1.3 to 2.0 mg/100 g DW. Iron (Fe) was

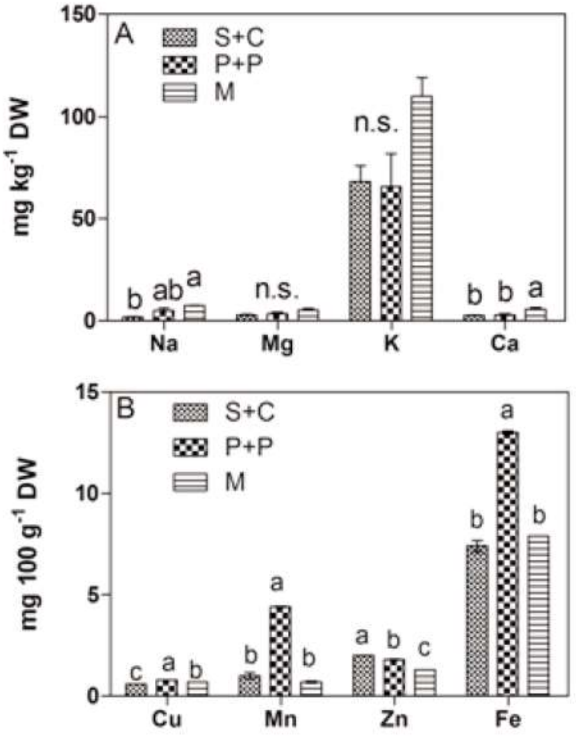

Fig. 3 - Nutritional elements expressed as mg/100 g dried weight. A) Na, Mg, K and Ca. B) Cu, Mn, Zn and Fe in tomato fruits harvested from plants grown in sand and coir (S+C), peat and perlite (P+P) or purchased at the local market (M Values are means with standard errors. Data were subjected to two-way ANOVA analysis and differences among means were determined using Bonferroni's post-test. Different letters indicate statistical differences for <0.05. The heavy metals in fruits were under the safety thresholds established by the European Union.

higher in fruits obtained from plants grown in the P+P substrates and the mean was 13.0 mg/100 g DW. Half the amount was found in fruits harvested from the S+C grown plants and purchased from local markets (Fig. 3).

Heavy metals were found in trace amounts and the values were below those set by EU regulations. The As content was higher in local market fruits (6.03 µg/kg DW), while in the SH system the As content was 0.63 µg/kg DW in fruits harvested from plants grown on the S+C substrate and 2.58 µg/kg DW in those obtained from plants grown on P+P substrate. Strontium (Sr) in the SH system ranged from 17.97 to 20.7 µg/kg DW, while in tomatoes purchased from the local market the concentration was 44.6 µg/kg DW on average (Fig. 4). Molybdenum (Mo) was 10-fold higher in fruits harvested from plants grown in the P+P substrate compared with S+C and local market tomato samples. Cadmium (Cd) was higher in fruits sold in local markets compared with those obtained from the SH system. The lowest value, 1.6 µg/kg DW, was found in fruits harvested from plants grown on the P+P substrate. Analogous results were observed for lead (Pb); the highest value found in fruits purchased from the market was 28.97 µg/kg DW (Fig. 4). On the contrary, higher Cr values were found in the fruits harvested from the SH system (21.03-45.67 µg/kg DW) compared with 16.83 µg/kg DW measured in the fruits purchased at the market (Fig. 4).

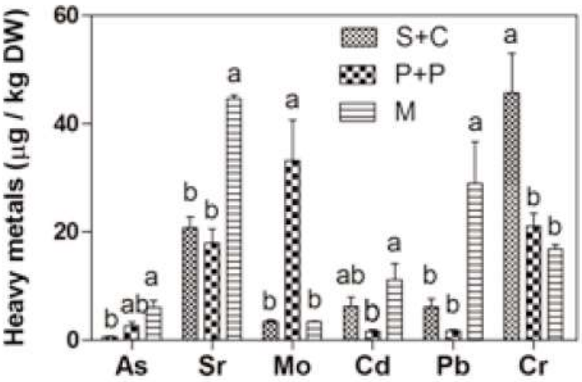

Fig. 4 - Heavy metals expressed as µg/kg DW determined in tomato fruits harvested from plants grown in sand and coir (S+C), peat+perlite (P+P) or purchased from the local market (M). Values are means with standard errors. Data were subjected to two-way ANOVA analysis and differences among means were determined using Bonferroni's post-test. Different letters indicate statistical differences for <0.05.

## 4. Discussion and Conclusions

The cultivation of vegetables in highly polluted environments where there is poor soil quality can only be achieved using soilless systems. Most people living in the slum areas do not have skills or knowledge about agricultural practises, therefore urban agricultural systems must be simple and easy to manage. Unfortunately, high density urban and peri-urban areas can also be subjected to heavy metal pollution. Contamination can also come from airborne trace elements such as Cd and Mo (Francini *et al.*, 2010) that are deposited on the surface of fruits. Heavy metal accumulation in vegetables is closely correlated with the pollution level of the area (Antisari *et al.*, 2015). SH is a good strategy to improve food security for urban slum populations and, in particular, it is linked to an increase of food availability (Orsini *et al.*, 2013). However, the food situation could also improve through direct sale of the products if the cultivated surface were enough to have a surplus of fresh produce. For these reasons it is important when choosing the cultivar to consider the most profitable ones in order to improve saleability of the products. The SH technique makes it possible to cultivate safe vegetables, in small spaces, and with low-tech instruments.

The results of the current study reveal that local materials for substrate and palm boxes were a good compromise between cost and production capability. The community of Al-Quarafa follows a typical Mediterranean diet based on cereals and legumes, however they do not consume fresh vegetables because they are very expensive and perishable (Arenas and Vavrina, 2002; Hamza and Mason, 2004). Thus, the application of SH represents an interesting method to combat food insecurity in Al-Quarafa, a symbol of all Cairo slums. Moreover, the use of the substrates in the study avoided the accumulation of heavy metals in vegetables and allowed enrichment of some of the micronutrients that improve human health.

SH have been used in Africa for 10 years to cultivate fresh products in urban and peri-urban settlements. For example in Dakar, in 1999 a FAO pilot project for family farming employed SH. The Dakar models, however, were adapted to tropical temperature and climate. The substrates were 40% peanut shells, 40% rice husks, and 20% perlite, suitable for leafy vegetable production because they are harvested at a young stage and do not have vertical growth.

Unfortunately, they are not able to support the growth of plants such as tomatoes. In fact, tomatoes prefer more stable substrates, from a mechanical point of view, such as peat/perlite or coir/sand (Esposito, 2010). Also the depth (14-20 cm) of the recycled-pallet boxes used in Dakar was less than that required by cultivated varieties that need greater volume for adequate root development to favour production (Ghehsareh *et al.*, 2011). The irrigation schedule in the Dakar project provided 2 L/m$^2$ two to three times a day (Ghehsareh *et al.*, 2011). The nutritional elements were recollected in a small container under the boxes. This daily schedule means that plants must be managed three times a day and this is one of the differences between the Dakar project and the method applied in the current study tested in Cairo in which an irrigation schedule was followed of once a week, thanks to the water capacity (WC) of the peat and coir. The combination of 50% coir and 50% sand provided the best growth performance for two reasons: 1) because using a weekly irrigation schedule the coir had greater WC than peat (Abad, 2002), and 2) because the weight of sand simplified the growth of the vegetative part of the plants, offering mechanical stability.

It is also important to consider the pH of the substrate used: the combination between coir and sand naturally had a sub acid pH (Arenas and Vavrina, 2002), with is the naturally ideal pH for tomato growth. This aspect favoured the availability of the micro and macro nutrients (Ghehsareh *et al.*, 2011). From a productive point of view, the tomato plants produced on average 0.4-0.5 kg per plant in the current investigation; the best results were achieved with tomatoes grown in sand/coir. Considering two plants per box, these values translate to a productive capability of 0.8-1 kg/m$^2$ of tomatoes on average. These productivity ranges consider the stressed conditions of the climate in Cairo which allows two growing cycles per year (September to November, March to June).

In terms of nutrition, considering the nutritional level of macro and micro elements of tomatoes analysed by the FDA, the tomatoes grown in SH in the current study had similar nutritional levels and sometimes better than the tomatoes the FDA considered as standard.

*Social agriculture and future strategy*

This SH growing system has been developed for poor urban communities with very limited agricultural knowledge. These cultivation systems are suitable for urban and social agriculture as reported in FAO guidelines. Moreover, for production in highly populated areas, SH systems also play a social role as they can be meeting points for the families within the community. Therefore, these growing systems should not be considered only as vegetable production tools. These systems must be easy to manage especially for water and nutrients supply. The management of the cultivation is often carried out by women and children, who are the most susceptible to food insecurity. In slum areas like Al-Quarafa, people are depressed, marginalized and unemployed. Hence, the growing areas improve food production, as well as the physic and psychological health of the inhabitants. Collaborations among the people living the community improve relationships between families and create opportunities to establish networks. These networks are essential to sharing information on crop cultivation in SH systems and to organising selling points in local market. In the future, the "Cairo model" of the SH system may be exported to other depressed urban areas in Africa and in the Middle East. This new, low-cost and low-tech growing system for vegetable production provides a great opportunity for poor populations who want to redeem themselves within society.

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