horticulturae

MDPI

Communication

Seed Germination and Seedling Growth on Knitted Fabrics as New Substrates for Hydroponic Systems

Jan Lukas Storck [1], Robin Böttjer [1], Dominik Vahle [1], Bennet Brockhagen [1], Timo Grothe [1], Karl-Josef Dietz [2], Anke Rattenholl [1], Frank Gudermann [1] and Andrea Ehrmann [1,*]

1 Faculty of Engineering and Mathematics, Bielefeld University of Applied Sciences, Interaktion 1, 33619 Bielefeld, Germany; Jan_Lukas.storck@fh-bielefeld.de (J.L.S.); Robin.boettjer@fh-bielefeld.de (R.B.); dominik.vahle@fh-bielefeld.de (D.V.); Bennet.brockhagen@fh-bielefeld.de (B.B.); timo.grothe@fh-bielefeld.de (T.G.); anke.rattenholl@fh-bielefeld.de (A.R.); Frank.gudermann@fh-bielefeld.de (F.G.)

2 Biochemistry and Physiology of Plants, Faculty of Biology, Bielefeld University, 33501 Bielefeld, Germany; Karl-Josef.dietz@uni-bielefeld.de

* Correspondence: andrea.ehrmann@fh-bielefeld.de

Received: 7 August 2019; Accepted: 17 October 2019; Published: 23 October 2019

Abstract: Vertical farming is one of the suggested avenues for producing food for the growing world population. Concentrating the cultivation of crops such as herbs in large indoor farms makes food production susceptible to technical, biological or other problems that might destroy large amounts of food at once. Thus, there is a trend towards locally, self-sufficient food production in vertical systems on a small scale. Our study examined whether conventional knitted fabrics, such as patches of worn jackets, can be used for hydroponics instead of the specialized nonwoven materials used in large-scale indoor systems. To this end, seed germination and seedling growth of 14 different crop plant species on knitted fabrics with three different stitch sizes were compared. Our results showed that hydroponic culture on knitted fabrics are indeed possible and allow for growing a broad spectrum of plant species, suggesting recycling of old textile fabrics for this purpose. Among the 14 plant species studied, differences in germination success, average fresh and dry masses, as well as water contents were found, but these parameters were not affected by knitted fabric stitch size.

Keywords: vertical farming; plant growth; textile fabrics; knitted fabrics; hydroponics

1. Introduction

In a climatically unreliable world, the requirement of feeding the growing number of people on earth becomes more and more challenging. Especially for cities, where agricultural production is farther away than from small villages, alternatives to common agricultural systems such as soilless cultivation may help provide food [1,2] and produce functional foods [3,4].

One of the alternative systems which has been developed recently is vertical farming, i.e., growing plants typically in large indoor farms [5] in hydroponic, aeroponic or aquaponic systems which are vertically stacked [6]. Vertical farming approaches allow for increasing crop yield per unit area [7].

Vertical farming has several advantages compared to conventional agriculture, such as reduced agricultural land use and correspondingly, more area available for natural ecosystems and associated ecosystem services, increased reliability of plant growth and harvest, reduced costs for storing and transporting food, reduced use of fertilizers and pesticides, and reduction of water consumption due to water recirculation [8]. Nevertheless, it should not be forgotten that there may also be disadvantages with vertical farming, such as high energy consumption for illumination and/or heating, inefficient use of space for important staple crops like wheat or corn, and possible economic ramifications due to the demand for space needed for vertical farming within cities.

Another issue associated with the dimensions of indoor farms is scale. Typically, they are managed by large companies, as opposed to traditional farms which are mostly run as family businesses, increasing possible dependence on few large enterprises. With large indoor farms, a complete loss of the harvest due to plant disease, technical malfunctions or insolvency would cause much larger problems than if production were spread across several local vertical farms. Indeed, combining vertical farming technologies with the idea of self-sufficient food production has raised much interest recently.

Simple hydroponic systems typically consist of plastic boxes with holes for the plants, with roots in water alone or an inert substrate. Technologically more sophisticated setups include illumination and irrigation [9]. To avoid production of unsustainable additional equipment for small-scale vertical hydroponic systems, however, it is worth thinking about alternatives, especially about recycling objects which are no longer useful for their initial purpose. An important aspect in hydroponics and aquaponics, and to a lesser extent in aeroponics, is the substrate on which the plants grow. This can be, e.g., rockwool [10], perlite [11,12], peat and sand, with sand and bark showing the greatest sustainability [13].

An alternative material class could consist of textile substrates. In contrast to sand or peat, textile substrates allow use of real hydroponic systems which do not replace soil with similar substrates. Unlike rockwool, knitted or woven fabrics can withstand mechanical stress, e.g., imposed by the roots growing through them, without being modified or destroyed, in this way making the substrate material more sustainable. Finally, textile fabrics offer a broad range of morphological properties including thickness, porosity, rigidity, bending resistance, etc., which can be tailored by choosing different textile technologies (especially weaving, warp or weft knitting) and different structures which can be produced by the respective technologies. Additionally, material properties cannot only be tailored by a chosen yarn, but also modified by an additional coating or finishing of the textile fabric.

Interestingly, we did not find any studies in the scientific literature on the utility of different textile substrates, such as woven, knitted and nonwoven materials, for hydroponic systems [14]. This is especially unexpected since textile fabrics enable tailoring material properties and structure independently to fit the needs of the roots of diverse crop plant species. More exactly, depending on the root dimensions and structures of the chosen species, it would be possible to construct textile fabrics with the desired stitch dimensions to let roots grow through them and at the same time to modify the thickness of the fabric to stabilize the roots so that stem orientation is fixed.

Recently, preliminary experiments were carried out with microalgae (*Chlamydomonas reinhardtii*) [15] and *Pleurotus ostreatus* mushroom mycelia [16] grown on fine nanofiber mats, and mushroom mycelia [17] or cress (*Lepidium sativum*) were grown [18] on knitted fabrics. In the present study, we evaluated seed germination and seedling growth of 14 different crop plant species on three knitted fabrics with differing stitch dimensions in a hydroponic system.

2. Materials and Methods

To enable comparison with a previous investigation of vertically mounted knitted fabric [18], the same fabrics were used here and consisted of polyacrylonitrile yarn (fineness 22/2, i.e., two threads with a linear weight of 1 g per 22 m each). Single-jersey samples of 5 cm × 5 cm were knitted on a hand flat knitting machine Silver Reed SK 280 (Knittax, Darmstadt, Germany) with needle gauge E5.6 (needle distance of 4.5 mm). Machine-specific stitch dimensions of 3, 5, and 7 (on a scale from 1–10) were used, resulting in the fabric parameters shown in Table 1. These dimensions were well knittable, without the danger of yarn break (for smaller stitch dimensions) or creating an overly loose fabric (for larger stitch dimensions). The areal weight was measured on an analytical balance SE-202 (VWR International GmbH, Darmstadt, Germany), while a digital gauge J-40-T (Wolf-Messtechnik GmbH, Freiberg, Germany) was used for thickness evaluation. Course and wale densities were investigated using a digital microscope VHX-600K (Keyence, Neu-Isenburg, Germany).

Table 1. Parameters of the knitted fabric used in this study.

Parameter	Stitch Size 3	Stitch Size 5	Stitch Size 7
Thickness (mm)	1.78	1.82	1.85
Areal weight (g/m^2)	211	196	181
Stitch length (mm)	10.3	12.0	13.7
Course density (cm^{-1})	5.1	4.4	3.7
Wale density (cm^{-1})	4.6	4.4	4.1

All samples were coated with Konjac Gum Powder (Special Ingredients, Chesterfield, UK), using a solution of 20.8 g/L in water, applied using a doctor blade. Konjac glucomannan is a polysaccharide strongly gelatinizing and binding water, extracted from *Amorphophallus konjac* [19] and often used in the food industry [20]. Before drying of the coating, 100 seeds were individually weighed to obtain mass per seed (Table 2), and then seeds of each plant species were placed in matrices of mostly 3 × 3 or 3 × 2 seeds on fabric samples with stitch sizes 3, 5, and 7. The following plant species were investigated:

- Chive (*Allium schoenoprasum*; Kiepenkerl, Bruno Nebelung GmbH, Everswinkel, Germany)
- Dill (*Anethum graveolens*; Kiepenkerl)
- Beet (*Beta vulgaris;* Gartenland GmbH Aschersleben, Essen, Germany)
- Kohlrabi (*Brassica oleracea*; Gartenland GmbH Aschersleben)
- Savoy cabbage (*Brassica oleracea*; Vertriebsgesellschaft Quedlinburger Saatgut mbH, Aschersleben, Germany)
- Chinese cabbage (*Brassica rapa*; Kiepenkerl)
- Pumpkin (*Cucurbita maxima;* Quedlinburger Saatgut)
- Carrot (*Daucus carota*; Gartenland)
- Lettuce (*Lactuca sativa*; Kiepenkerl)
- Common basil (*Ocimum basilicum*; Quedlinburger Saatgut)
- Garden parsley (*Petroselinum crispum*; Gartenland)
- Spinach A (*Spinacia oleracea*; Kiepenkerl)
- Spinach B (*Spinacia oleracea*; Quedlinburger Saatgut)
- Corn (*Zea mays* ssp. *mays* L.; Floraself, Hornbach Baumarkt AG, Bornheim, Germany).

Either 9 seeds per sample (spinach A, chive, Chinese cabbage and garden parsley), 1 seed per sample (corn and pumpkin) or 6 seeds per sample (all other species) were placed on the coated knitted fabrics, depending on the dimensions of the seeds and the expected plant growth. Finally, the coating with seeds was left to dry at room temperature.

Our main goal was to evaluate which species may generally be suitable for growing on textile fabrics in a hydroponic system in this first proof-of-principle study. We assumed that possible variations due to different seed batches, varying seasons, etc., would not change the results determining which species were in general suitable to be grown in such a system. To this end, this first test series was performed as one experiment with sufficient seeds per plant species (except for corn and pumpkin) to calculate reliable mean values and standard deviations.

The hydroponic test stand is shown in Figure 1. Using chicken wire, the textile fabrics were held at a constant water level in the upper boxes, with the lower box serving as a reservoir. A Heissner smartline HSP600-00 pump (Heissner, Lauterbach, Germany) was used to ensure slow water circulation in order to avoid the spread of possible contamination of the water reservoirs with microalgae or mold fungi, as successfully tested in prior experiments. Inside the boxes, water was used with a water hardness level of 16 °d, i.e., 16 degrees of hardness, or what is considered “hard” water. Nutrients were not added to the tap water since only the germination process and early growth phase were examined for which the nutrient supply from the seeds was expected to be sufficient.

Figure 1. Hydroponic test stand used in this study.

Illumination was provided by 2 LED tubes (TubeKIT LED 1.5 m 21.5W/830, Osram, Munich, Germany) with a 150 cm length, color temperature of 3000 K, 21.5 W power, 150° angle of irradiation and luminous flux of 1890 lm, using 16 h light and 8 h dark periods, which provided low light intensities of 8.1 W/m^2 ± 1.7 W/m^2, as measured by a solarimeter (KIMO SL-200, Kimo Instruments, Chevry-Cossigny, France). These light intensities are similar to the light compensation point of many crop plant species, e.g., radish at 7 W/m^2 [21], so that only a small increase in dry mass was expected due to low photosynthetic CO_2 assimilation rates. Such low-light conditions are of interest economically in order to reduce the energy needed for illumination of a hydroponic system, especially in an environment where no specialized lamps would be added to commonly-used lighting due to cost. The lights were, nevertheless, sufficient to induce phototropism and thus oriented growth of the stems towards the light sources and allowed photosynthetic compensation of the respiratory loss of CO_2 [22]. These low light intensities were chosen to evaluate the germination process under low-energy consumption and thus under relatively sustainable conditions.

Table 2. Characterization of the seeds used in this study, sorted by the seed mass (N = 100).

Species	Individual Seed Mass (mg)	Group	Requirement of Light for Germination
Corn	145 ± 16	Monocots	No [23]
Pumpkin	107 ± 8	Dicots	No [24]
Beet	16 ± 6	Dicots	No [25]
Spinach A	17.5 ± 1.6	Dicots	No [26]
Spinach B	17.3 ± 1.3	Dicots	No [26]
Kohlrabi	3.1 ± 0.9	Dicots	Yes [26]
Savoy cabbage	2.4 ± 0.4	Dicots	No [26]
Chinese cabbage	2.8 ± 0.3	Dicots	No [26]
Lettuce	1.2 ± 0.3	Dicots	Yes [27–29]
Garden parsley	1.9 ± 0.3	Dicots	No [26]
Common basil	1.7 ± 0.3	Dicots	Yes [26]
Chive	1.48 ± 0.22	Monocots	No [26]
Dill	1.30 ± 0.23	Dicots	Yes [28]
Carrot	0.86 ± 0.18	Dicots	Yes [26]

Plant growth was evaluated after 31 d. Fresh shoot tissue biomass of each seedling, cut directly above the textile fabric and after wiping it dry, was quantified on an analytical balance [10]. For drying, the tissues were put into a universal heating cabinet UN 75 (Memmert, Schwabach, Germany) at 60 °C for 48 h and then weighed.

Percent germination, and fresh and dry masses were compared. Calculations were performed using IBM SPSS Statistics 26 for the case of nonhomogeneous variances, and means were compared using paired comparisons by Student *t*-test at $P < 0.05$.

3. Results and Discussion

The percent germination of each species per textile fabric are presented in Table 3. At the end of the experiment, it could clearly be distinguished whether a seed germinated or not, in contrast to the first days when only the radicle of the seedling became visible.

Table 3. Percentage of germinated seeds per fabric, sorted by average germination success.

Species	Stitch Size 3	Stitch Size 5	Stitch Size 7	Average
		% Germination		
Dill	100	100	100	100 a [z]
Savoy cabbage	100	100	100	100 a
Carrot	100	100	100	100 a
Lettuce	100	100	100	100 a
Pumpkin	100	100	100	100
Corn	100	100	100	100
Kohlrabi	67	83	83	77 ± 10 ab
Chive	67	67	67	67 b
Chinese cabbage	67	67	67	67 b
Beet	67	33	100	67 ± 34 abc
Garden parsley	67	56	67	63 ± 6 b
Common basil	83	50	50	61 ± 19 abc
Spinach A	33	33	45	37 ± 7 c
Spinach B	50	17	17	28 ± 19 c
Average	77 ± 27 a	70 ± 32 a	77 ± 31 a	

[z] Means followed by different letters are significantly different by the student's t-test at $P < 0.05$. For pumpkin and corn, only one seed per fabric was used so they were not included in the statistical analysis.

Firstly, it was clear that for dill, savoy cabbage, carrot and lettuce, all seeds germinated. This was also true for pumpkin and corn; however, it must be kept in mind that there was only one seed per textile sample of these large-seeded species.

Both varieties of spinach had the lowest germination percentages. The missing standard deviations for some of the species due to identical germination on all three knitted fabrics, combined with the relatively small number of seeds, reduced the reliability of the stochastic assessment. Nevertheless, the differences between the several species with approx. 100% germination and a few species with very low germination, such as spinach, were obvious.

For the different stitch sizes of the knitted fabrics, no significant differences occurred, as visible by the overlapping standard deviations. As was expected, the dimensions of the pores or holes in the substrate are irrelevant for the germination process.

To determine if pore size affected seedling growth after germination, fresh and dry masses were evaluated independently for the three different stitch sizes, as presented in Tables 4 and 5, respectively. Table 4 shows the average fresh mass of the plant shoots, cut directly at the surface of the textile substrates. Stitch size had no effect on fresh mass across species. It can be assumed that the pores between the knitted yarns were in all cases large enough to allow the roots to penetrate through them without a problem. This finding underlines that the knitted fabrics examined here, using an intermediate machine fineness similar to the size usually used for knitted jackets, are well suited for growth of a broad spectrum of species.

Table 4. Fresh masses per seedling of shoot tissue above the textile fabrics, sorted by the average fresh mass. An * indicates the two pumpkin seedlings whose integuments were still attached and which thus were included in the mass.

Species	Stitch Size 3	Stitch Size 5	Stitch Size 7	Average
		Fresh Mass (g)		
Pumpkin	0.45	1.07 *	1.64 *	1.1 ± 0.6
Corn	0.24	0.71	0.63	0.53 ± 0.25
Spinach A	0.16	0.17	0.12	0.15 ± 0.03
Kohlrabi	0.20	0.12	0.14	0.15 ± 0.04
Chinese cabbage	0.127	0.127	0.145	0.133 ± 0.010
Savoy cabbage	0.17	0.10	0.09	0.12 ± 0.04
Beet	0.10	0.16	0.09	0.12 ± 0.04
Spinach B	0.09	0.07	0.10	0.087 ± 0.015
Common basil	0.045	0.069	0.087	0.067 ± 0.021
Lettuce	0.041	0.041	0.067	0.050 ± 0.015
Carrot	0.027	0.028	0.018	0.024 ± 0.005
Garden parsley	0.021	0.022	0.028	0.024 ± 0.004
Chive	0.028	0.022	0.017	0.022 ± 0.006
Dill	0.01	0.013	0.013	0.012 ± 0.002
Average (w/o pumpkin)	0.085 ± 0.063 a [z]	0.091 ± 0.070 a	0.086 ± 0.059 a	

[z] Means followed by different letters are significantly different by Student's t-test at $P < 0.05$.

Table 5. Dry masses per seedling of shoots above the textile fabrics, sorted by the average dry mass.

Species	Stitch Size 3	Stitch Size 5	Stitch Size 7	Average
		Dry Mass (g)		
Pumpkin	0.029	0.088	0.104	0.07 ± 0.04
Corn	0.021	0.064	0.058	0.048 ± 0.023
Spinach A	0.012	0.027	0.013	0.017 ± 0.008
Savoy cabbage	0.018	0.011	0.009	0.013 ± 0.005
Chinese cabbage	0.014	0.012	0.012	0.0127 ± 0.0012
Kohlrabi	0.017	0.010	0.010	0.012 ± 0.004
Spinach B	0.017	0.010	0.010	0.012 ± 0.004
Beet	0.0053	0.0065	0.0085	0.0068 ± 0.0016
Lettuce	0.0057	0.0052	0.0057	0.0055 ± 0.0003
Common basil	0.0034	0.0043	0.0077	0.0051 ± 0.0023
Carrot	0.0037	0.0038	0.0017	0.0031 ± 0.0012
Garden parsley	0.0028	0.0028	0.0037	0.0031 ± 0.0005
Chive	0.0027	0.0020	0.0015	0.0021 ± 0.0006
Dill	0.0013	0.0015	0.0015	0.00143 ± 0.00012
Average (w/o pumpkin)	0.010 ± 0.007 a [z]	0.012 ± 0.017 a	0.011 ± 0.015 a	

[z] Means followed by different letters are significantly different by the student's t-test at $P < 0.05$.

It should be mentioned that calculating the individual biomass per plant by subtracting the seed mass from the full plant (dry or fresh) mass, as suggested by Lennard and Ward [10], was not possible since the roots were fixed inside the textile fabrics and were thus prone to being damaged or even broken during removal from the substrates. As an example, Figure 2 shows the roots of savoy cabbage after the end of the experiment.

Figure 2. Roots of savoy cabbage after one month of growth.

Dry masses are often a better estimate of the growth success. Therefore, dry masses were also determined for the different species grown on the fabrics (Table 5). The order of the species, sorted by dry mass, did not significantly change. Again, the values averaged over the fabrics with equal stitch sizes were similar to the results of the fresh mass evaluation. This confirmed that knitted fabrics of different stitch sizes are suitable as germination and early growth substrates for diverse plant species.

Table 6 presents the dry mass as percentage of wet mass. Generally, this value was always in the order of magnitude of 10%. There was possibly a tendency for the plants with higher relative dry mass to have a higher percent germination (Table 3). Again, no significant effect of the stitch dimension was evident.

Table 6. Shoot dry mass-to-fresh mass percentages, sorted by the average percentage.

Species	Stitch Size 3	Stitch Size 5	Stitch Size 7	Average
		Dry Mass/Fresh Mass (%)		
Spinach B	18.89	14.29	10.00	14 ± 4
Garden parsley	13.33	12.73	13.21	13.1 ± 0.3
Carrot	13.70	13.57	9.44	12.2. ± 2.4
Dill	13.00	11.54	11.54	12.0 ± 0.8
Lettuce	13.90	12.68	8.51	11.7. ± 2.8
Spinach A	7.50	15.88	10.83	11 ± 4
Savoy cabbage	10.59	11.00	10.00	10.5 ± 0.5
Chinese cabbage	11.02	9.45	8.28	9.6 ± 1.4
Chive	9.64	9.09	8.82	9.2 ± 0.4
Corn	8.82	8.99	9.22	9.01 ± 0.20
Kohlrabi	8.50	8.33	7.14	8.0 ± 0.7
Common basil	7.56	6.23	8.85	7.5 ± 1.3
Pumpkin	6.44	8.22	6.34	7.0 ± 1.1
Beet	5.30	4.06	9.44	6.3 ± 2.8
Average (w/o pumpkin)	10 ± 4 a [Z]	10 ± 3 a	9.4 ± 1.7 a	

[z] Means followed by different letters are significantly different by the student's t-test at $P < 0.05$.

One possible effect on seedling growth, wet and dry mass, might be expected due to the group of angiosperms to which the species under investigation belong, i.e., monocots (corn and chive) or dicots (all other species) since this difference defines the shape of the root. Monocots usually have many similar fine roots and are homorhizous, while dicots display a main root and lateral roots of first, second and third order and are heterorhizous. Comparing the two monocots in this study with the dicot species, however, showed differing fresh and dry masses for the monocots (the germination success cannot be compared due to the low number of seeds for corn), while they were both at similar percentage dry mass values.

Some plant species depend on light for germination, i.e., lettuce, common basil, dill and carrot. However, the required light intensity is extremely low and triggers cell communication and is not required as an energy source. Thus, light-dependent germination is triggered by the phytochrome system which responds to low red light quantities [30]. This feature may explain why lettuce, carrot and dill showed 100% germination; only germination of common basil was below average. Stronger illumination, significantly above the light compensation points, should be used in follow-up studies to investigate longer-term seedling growth on the fabrics.

In summary, the stitch size of the knitted fabrics did not influence the growth of the seedlings during the first 31 days.

4. Conclusions

Different plant species were investigated for germination and growth on knitted fabrics in hydroponic systems. Importantly, each fabric supported growth of the various plant species for 31 d after germination, underlining the general possibility of using knitted fabrics as substrates in vertical farming. It was also shown that this could be used for all plant species in the study so that a broad range of species can be expected to be able to grow on knitted fabrics in a hydroponic system. The percentage germination, average fresh and dry masses as well as the relative dry masses, were not affected by the knitted fabric stitch size. Light levels will be tested in detailed follow-up studies to evaluate whether weak indoor light is sufficient for plant growth in a textile-based hydroculture, in this way possibly enabling vertical farming in private households without the necessity of applying additional light and thus additional energy.

Author Contributions: Conceptualization, J.L.S. and R.B.; methodology, J.L.S., R.B. and K.-J.D.; validation, K.-J.D., A.R. and F.G.; formal analysis, J.L.S.; investigation, J.L.S., R.B., D.V., B.B. and T.G.; Writing—Original draft preparation, A.E.; Writing—Review and editing, all authors; visualization, J.L.S. and T.G.; supervision, A.E.

Funding: The project was partly funded by the Federal Ministry for Economic Affairs and Energy in the scope of the ZIM project ZF4036107 and by the HiF fund of Bielefeld University of Applied Sciences. The APC is funded by the Open Access Publication Fund of Bielefeld University of Applied Sciences and the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation)–414001623.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Januszkiewicz, K.; Jarmusz, M. Envisioning urban farming for food security during the climate change era. Vertical farm within highly urbanized areas. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *245*, 052094. [CrossRef]
2. Rouphael, Y.; Kyriacou, M.C.; Colla, G. Vegetable grafting: A toolbox for securing yield stability under multiple stress conditions. *Front. Plant Sci.* **2018**, *8*, 2255. [CrossRef] [PubMed]
3. Sabatino, L.; D'Anna, F.; D'Anna, F.; Iapichino, G.; Moncada, A.; D'Anna, E.; De Pasquale, C. Interactive effects of genotype and molybdenum supply on yield and overall fruit quality of tomato. *Front. Plant Sci.* **2019**, *9*, 1922. [CrossRef] [PubMed]
4. Sabatino, L.; Ntatsi, G.; Iapichino, G.; D'Anna, F.; De Pasquale, C. Effect of selenium enrichment and type of application on yield, functional quality and mineral composition of curly endive grown in a hydroponic System. *Agronomy* **2019**, *9*, 207. [CrossRef]
5. Despommier, D. Farming up the city: The rise of urban vertical farms. *Trends Biotechnol.* **2013**, *31*, 388–389. [CrossRef]
6. Al-Chalabi, M. Vertical farming: Skyscraper sustainability? *Sustain. Cities Soc.* **2015**, *18*, 74–77. [CrossRef]
7. Touliatos, D.; Dodd, I.C.; Mc-Ainsh, M. Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food Energy Secur.* **2016**, *5*, 184–191. [CrossRef]
8. Pinstrup-Anderson, P. Is it time to take vertical indoor farming seriously? *Glob. Food Secur.* **2018**, *17*, 233–235. [CrossRef]
9. Agrilution–Your Vertical Farming System. Available online: https://agrilution.com/ (accessed on 28 July 2019).

10. Lennard, W.; Ward, J. A comparison of plant growth rates between an NFT hydroponic system and an NFT aquaponic System. *Horticulturae* **2019**, *5*, 27. [CrossRef]
11. Camara-Zapata, J.M.; Brotons-Martinez, J.M.; Simon-Grao, S.; Martinez-Nicolas, J.J.; Garcia-Sanchez, F. Cost-benefit analysis of tomato in soilless culture systems with saline water under greenhouse conditions. *J. Sci. Food Agric.* **2019**. [CrossRef]
12. Rodriguez-Ortega, W.M.; Martinez, V.; Nieves, M.; Simon, I.; Lidon, V.; Fernandez-Zapata, J.C.; Martinez-Nicolas, J.J.; Camara-Zapata, J.M.; Garcia-Sanchez, F. Agricultural and physiological responses of tomato plants grown in different soilless culture systems with saline water under greenhouse conditions. *Sci. Rep.* **2019**, *9*, 6733. [CrossRef] [PubMed]
13. Vinci, G.; Rapa, M. Hydroponic cultivation: Life cycle assessment of substrate choice. *Br. Food J.* **2019**, *121*, 1801–1812. [CrossRef]
14. Ehrmann, A. On the possible use of textile fabrics for vertical farming. *Tekstilec* **2019**, *62*, 34–41. [CrossRef]
15. Großerhode, C.; Wehlage, D.; Grothe, T.; Grimmelsmann, N.; Fuchs, S.; Hartmann, J.; Mazur, P.; Reschke, V.; Siemens, H.; Rattenholl, A.; et al. Investigation of microalgae growth on electrospun nanofiber mats. *AIMS Bioeng.* **2017**, *4*, 376–385. [CrossRef]
16. Sabantina, L.; Kinzel, F.; Hauser, T.; Többer, A.; Klöcker, M.; Döpke, C.; Böttjer, R.; Wehlage, D.; Rattenholl, A.; Ehrmann, A. Comparative study of *Pleurotus ostreatus* mushroom grown on modified PAN nanofiber mats. *Nanomaterials* **2019**, *9*, 475. [CrossRef]
17. Helberg, J.; Klöcker, M.; Sabantina, L.; Storck, J.L.; Böttjer, R.; Brockhagen, B.; Kinzel, F.; Rattenholl, A.; Ehrmann, A. Growth of *Pleurotus ostreatus* on different textile materials for vertical farming. *Materials* **2019**, *12*, 2270. [CrossRef]
18. Böttjer, R.; Storck, J.L.; Vahle, D.; Brockhagen, B.; Grothe, T.; Herbst, S.; Dietz, K.-J.; Rattenholl, A.; Gudermann, F.; Ehrmann, A. Influence of textile and environmental parameters on plant growth on vertically mounted knitted fabrics. *Tekstilec* **2019**, *62*, 200–207. [CrossRef]
19. Zhu, F. Modification of konjac glucomannan for diverse applications. *Food Chem.* **2018**, *256*, 419–426. [CrossRef]
20. Zhang, H.; Cui, S.; Lv, H.; Pei, X.J.; Gao, M.J.; Chen, S.N.; Hu, J.; Zhou, Y.; Liu, Y.C. A crosslinking strategy to make neutral polysaccharide nanofibers robust and biocompatible: With Konjac glucomannan as an example. *Carbohydr. Polym.* **2019**, *215*, 130–136. [CrossRef]
21. Oh, S.; Moon, K.H.; Song, E.Y.; Son, I.-C.; Koh, S.C. Photosynthesis of Chinese cabbage and radish in response to rising leaf temperature during spring. *Hortic. Environ. Biotechnol.* **2015**, *56*, 159–166. [CrossRef]
22. Christie, J.M. Phototropin blue-light receptors. *Annu. Rev. Plant Biol.* **2007**, *58*, 21–45. [CrossRef] [PubMed]
23. Idikut, L. The effects of light, temperature and salinity on seed germination of three maize forms. *Green. J. Agric. Sci.* **2013**, *3*, 246–253. [CrossRef]
24. Motsa, M.M.; Slabbert, M.M.; van Averbeke, W.; Morey, L. Effect of light and temperature on seed germination of selected African leafy vegetables. *S. Afr. J. Bot.* **2015**, *99*, 29–35. [CrossRef]
25. Hunter, J.R. Some Factors Affecting Germination in Sugar Beet Seeds (*Beta vulgaris* L.). Ph.D. Thesis, State College of Agriculture and Applied Sciences, East Lansing, MI, USA, 1951.
26. Elis, R.H. *Handbook of Seed Technology for Genebanks: Compendium of Specific Germination*; International Board for Plant Genetic Resources: Rome, Italy, 1985.
27. Ingram, D.S.; Vince-Prue, D.; Gregory, P.J. Chapter 9: Raising Plants from Seed. In *Science and the Garden: The Scientific Basis of Horticultural Practice*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
28. Reilly, A. *Starting Seeds Indoors*; Storey Publishing, LLC: North Adams, MA, USA, 1988.
29. Di Girolami, G.; Barbanti, L. Treatment conditions and biochemical processes influencing seed priming effectiveness. *Ital. J. Agron.* **2012**, *7*, 178–188. [CrossRef]
30. Nagy, F.; Schafer, E. Phytochromes control photomorphogenesis by differentially regulated, interacting signaling pathways in higher plants. *Annu. Rev. Plant Biol.* **2002**, *53*, 329–355. [CrossRef]