Hungarian University of Agriculture and Life Sciences

Effect of water supply on Physiological Factors and Response to Gamma Irradiation of Phytonutrients in Chilli pepper cultivars *(Capsicum* sp.)

Thesis for the degree of PhD in Crop Production and Horticulture Sciences

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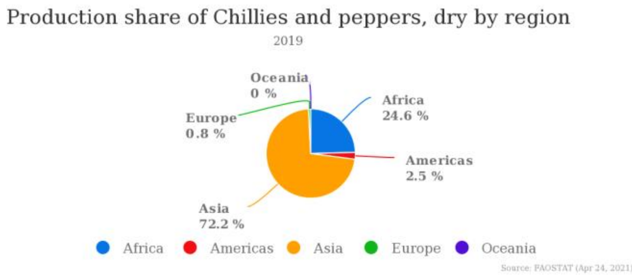
1.0 INTRODUCTION

1.1 Background

Pepper (*Capsicum species*) is a genus of the Solanaceae family and is commonly divided into two significant groups known as pungent and non-pungent, one of the oldest, most popular, beneficial, and economical vegetable spices in the whole world. Chilli pepper fruits *(Capsicum sp.)* are continuously increasing across the entire world, which has improved livelihood and income resources. Hot pepper is commonly grown and consumed in countries like China, Korea, and many other places.



Several factors affect crop production and productivity, of which climate is one of the primary contributing determinants of yield and is expected to influence crop quality. Chilli pepper crop requires the right and precise amount of water for high yield and fruit quality. The use of drip irrigation is an opportunity for precise water application and nutrients or fertigation to crops. Spices such as red peppers are frequently exposed to insects and microorganisms during cultivation and storage, which may be potential contamination sources in foods. One of the oldest techniques to prevent the deterioration of chilli is drying.

In Hungary, spice red peppers and chillies are traditionally sun-dried. The farmers dry their peppers on the walls around their houses inside a mesh bag. For mass production, thermal drying with air current in drying tunnels is mainly used. The use of the hot drying preservation method affects macronutrients which degrade micronutrients, polyphenols, flavonoids, antioxidants. Irradiation of dried spices is widely recognised and legally accepted in at least 51 countries worldwide, with a maximum overall average of 10 kGy.

1.2 Objectives to achieve

1. To study the important physiological factors affecting different chilli pepper cultivars
2. To study the water supply and marketable yield of the various chilli pepper plants
3. To characterise by recent analytical protocols, the phytonutrients (vitamin C, capsaicinoids, carotenoids, and tocopherols) in the chilli peppers
4. To study the response of phytonutrients to gamma irradiation treatments and change over-ripening stages with retaining the levels of phytonutrients at acceptable measure.

2.0 MATERIALS AND METHODS

2.1 Experimental conditions

Chilli pepper cultivars 'Hetényi Parázs' (HET), 'Unikal' (UNIK), 'Unijol' (UNIJ), and Habanero (HAB) seedlings were obtained from Univer Product Zrt, the leading food industry in Hungary. After 40 days of germination in a nursery, the seedlings were transported for open field cultivation on May 17, 2018, and May 13, 2019, each season against three (3) different water supply treatments; 0% (control except for natural precipitation), 50% deficit irrigation and 100% optimum water supply. The entire experiment was arranged in a randomised complete block design (RCBD) with four replicates or blocks per treatment on a one-hectare plot of land.

2.2 Irrigation system and management

Irrigation was set up using a drip system for both experimental seasons. A pressure gauge and water meter were installed with control valves in each treatment to manually adjust the water pressure, depth of water supply, and uniformity of water and distribution. The crop water requirement (ETc) was measured based on the AquaCrop model by Food and Agriculture Organization to determine evapotranspiration (ETo) using the Penman-Monteith method corrected by a crop coefficient (Kc) (Table 1, fig 3). Generally, irrigation of plants was done two times per week depending on precipitation, and once a week, plants received uniform fertilisation in the form of granulates proportion of nitrogen (NO_3), phosphorus (P_2O_5), and potassium (K_2O) YaraMila Complex 12–11–18 + 20% sulphur (SO_3) (Yara & Co., Veszprem, Hungary).

During the plant growth periods (2018 and 2019), healthy and newly emerged plant leaves were randomly selected in replicates for relative chlorophyll content (expressed as SPAD values), leaf chlorophyll fluorescence (Fv/Fm), and canopy temperature (°C) measurements, phytonutrients in fresh and irradiated peppers.

Table 1. Meteorological record and water supply throughout the chilli pepper growing seasons

Year	Mean temperature (°C)	Mean relative humidity (%)	Precipitation and rainfall (mm)	Irrigation (mm)		Total water received by plants (mm)[1]		
				50%	100%	0%	50%	100%
2018	23.8	71	347.8	132.6	272.2	347.8	480.4	620.0
2019	25.8	72.3	132.6	152.2	289.0	132.6	284.4	421.6

[1]0%, control; 50%, deficit irrigation; 100%, optimum water supply

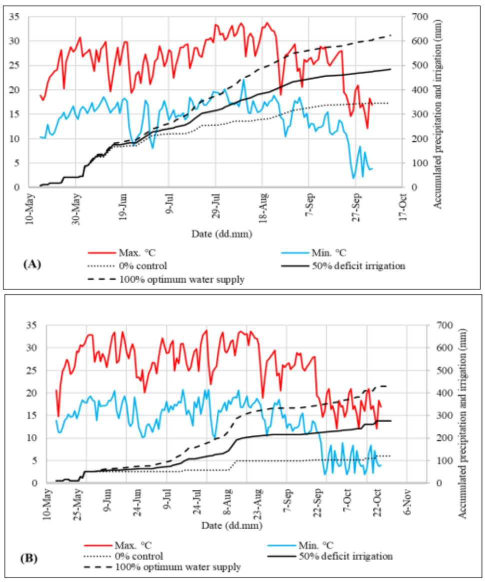


Figure 3. Trends of daily maximum (Max.) and minimum (Min.) air temperature (°C), and accumulated precipitation and irrigation (mm) for the growing seasons, dated May 05, 2018 – October 17, 2018 **(A)** and May 05, 2019 – November 11, 2019 **(B)**.

2.3 Statistical analysis

Data were expressed as the mean ± standard deviation (SD) among physiological responses, pepper cultivars, water supply treatments, and phytonutrients. The Kolmogorov-Smirnov test was used to decide if samples come from populations with a normal distribution. Levene's test was used to test the variance's homoscedasticity, where the null hypothesis is that the variances within each of the examined groups are the same. One-way analysis of variance (ANOVA) was used to examine the effect of water supply on physiological responses and two-way ANOVA for vitamin C, capsaicinoids, tocopherols and carotenoids.

3.0 RESULTS AND DISCUSSION

3.1 Yield

The marketable yield measured at their fresh base weight, depending on water supply treatments, 0% and 50%, produced a higher quantity in the second harvest. HET, UNIK, and UNIJ produced marketable yield in the second harvest, in HAB during the third harvest, and in minimum quantity for the subsequent harvest. Pepper cultivars responded well to yield under non-irrigated and 50% deficit.

Table 2: The average yield of the peppers cultivated in 2018 (n = 4; mean ± SD) based on fresh weight (t/ha)

Cultivar	Water supply treatments	1st harvest	2nd harvest	3rd harvest	4th harvest	Total yield (t/ha)
HET	0%	3.55±0.86Ba	10.39±2.27Ca	2.31±0.57Ba	0.36±0.07Aa	16.62±0.94a
	50%	3.6±0.72Ba	11.95±3.23Ca	2.43±0.45Ba	0.36±0.03Aa	18.34±1.11b
	100%	3.17±0.77Ba	10.39±2.36Ca	1.72±0.37Aa	0.36±0.10Aa	15.64±0.90a
UNIK	0%	1.86±0.37Aa	9.86±1.76Ca	4.18±1.33Ba	-	15.9±1.16a
	50%	2.05±0.47Aa	10.52±1.91Ca	7.1±1.28Bb	-	19.67±1.22b
	100%	1.97±0.42Aa	9.02±2.07Ca	4.26±0.81Ba	-	15.25±1.10a
UNIJ	0%	0.85±0.24Aa	6.64±1.55Ca	2.58±0.17Ba	0.36±0.03Aa	10.43±0.50a
	50%	0.92±0.30Aa	10.02±3.31Bb	1.62±0.34Aa	0.24±0.03Aa	12.8±1.00b
	100%	0.52±0.10Aa	6.89±1.84a	1.26±0.20Aa	0.24±0.03Aa	8.92±0.54a
HAB	0%	1.81±0.55Ab	5.63±3.32Bb	0.48±0.24Aa		7.92±0.79b
	50%	2.19±1.25Bb	5.41±1.96Cb	0.36±0.07Aa		7.96±1.09b
	100%	0.55±0.20Aa	3.32±0.63Ba	0.24±0.06Aa		4.11±0.30a

Uppercase letters in the first data row and the lowercase letters in the first data column. Upper letter represents harvest periods, lower case represents water supply according to Tukey's HSD post hoc test

3.2 Phytonutrients

Based on the phytochemical response of fresh peppers to water supply treatments, capsaicinoid concentration was higher in UNIJ, HET, and HAB under non-irrigated conditions and 50% deficit and also lower concentration in UNIK. A lower level of pungency was recorded in all cultivars when they were given optimum water supply. Depending on the effect of harvesting periods on pungency concentration, high amounts were found in the second and third harvests. The major capsaicinoids concentration (capsaicin, dihydrocapsaicin, and nordihydrocapsaicin) was high in the second growing season when compared to the first year. However, in both years, the homologue compounds (homocapsaicin, dihydrocapsaicin isomer, homodihydrocapsaicins) were found in minimal quantities. Capsaicin was high in HET in 2019 (584.1±19.14 µg/g) and lower in 2018 (310.1±46.28 µg/g) under 0% or control and 50% deficit irrigation conditions. In contrast, in the case of UNIJ and HAB, capsaicin was lower in 2019 (UNIJ, 1936.3±216.53 µg/g; HAB, 2549.7±80.97 µg/g) and high in 2018 (UNIJ, 6518.7±764.47 µg/g; HAB, 3564.7±150.25 µg/g).

Vitamin C content was found in all harvests for both years. Between water supply treatments, higher amounts were recorded in 0% and 50%. A lower vitamin C content was found in optimum water. HET, UNIK, and UNIJ had higher amounts of vitamin C whereas lower amounts were found in HAB (varied between 596.8±134.59 µg/g – 636.2±69.10 µg/g) in the first year. However, HAB had higher vitamin C in the second year, which varied between 2870.0±148.81 µg/g – 3223.7±118.61 µg/g. Vitamin C content was higher in 2019 than in 2018, under 0% and 50% and lowered in 100%. This indicated that accumulated precipitation and irrigation in 2019 was more optimal for vitamin C content.

All the cultivars had an influence on the major compounds Tocopherols (vitamin E), γ-tocopherol, α-tocopherol, and β-tocopherol. Lower concentrations of γ-toc and β-toc were observed in all cultivars irrespective of the water supply treatments, UNIK (2.2±0.5 µg/g) and HET (2.0±2.32 µg/g) recorded concentration of β-toc under 0% and 50%. Also, α-toc concentration was significantly lower in 100%. The concentration of α-toc under 0% was found to be higher in HET (between 76.6±6.17 µg/g

– 81.4±4.60 µg/g) and lower in HAB (between 7.10±4.8 µg/g – 10.4±1.15 µg/g) during the first growing season. However, by the second growing season, a decrease in tocopherol concentration was observed in all cultivars (HET, UNIK, UNIJ, and HAB). A lower concentration of γ-toc was evident in all cultivars irrespective of the water supply treatments. The concentration of α-toc was found to be higher in 0% in HET (between 58.1±7.1 µg/g – 69.0±1.7 µg/g) and lower in HAB (between 1.7±0.78 µg/g – 0.1±0.03 µg/g). β-toc was absent or in minimal amounts in all cultivars.

Tocopherol concentration was found to be lower, especially under optimum water in both study periods. However, tocopherol concentration was found to be higher in the first growing season when compared to the second year. It was observed in this study that tocopherol concentration decreased as accumulated precipitation and irrigation increased, and therefore, under a moderate temperature, tocopherol concentration may increase. Based on water supply treatments, 50% had minimal influence on tocopherol concentration. This indicates that 50% may not be relevant for tocopherols (vitamin E) since it did not increase or decrease tocopherol concentration. However, maintaining no irrigation (an exception to natural precipitation), tocopherol concentration may increase or stabilise.

In the case of total carotenoids concentration, the analysed peaks (Free capsanthin, Free zeaxanthin, Capsanthin mono-esters, Zeaxanthin mono-esters, Beta carotene, Capsanthin di-esters, Zeaxanthin di-esters) were characterised depending on their relevance in food chemistry. Capsanthin gives the primary red colour of peppers, zeaxanthin represents the yellow colour during ripening, and β-carotene is essential from the nutritional point of view. A higher concentration of Free caps was found in UNIK peppers (64.56±11.2 µg/g) under the non-irrigated condition in the third harvest and lower in HAB (0.16±0.01 µg/g) in 2018. By the second growing season, Free caps concentration decreased in HET (2.76±0.47 µg/g) and UNIK (3.48±0.51 µg/g), as well as in HAB (0.07±0.03 µg/g). A similar trend was observed in the concentration of Caps ME and Caps DE in both years. Free zeax was higher in UNIK (16.08±3.85 µg/g) under the third harvest (0%) and lower in UNIJ (0.21±0.06 µg/g) under 100% and absent in HAB. However, in 2019 Free zeax concentration was higher in HET (15.08±3.51 µg/g) and UNIK (16.08±9.93 µg/g) and lower in HAB (0.04±0.01 µg/g) when compared to the concentration of HET (4.09±1.47 µg/g), UNIK (5.24±1.41 µg/g) and HAB (0.37±0.17 µg/g; not detected) in 2018. Similarly, Zeax ME concentration was higher in UNIK and lower in HAB in both years. However, in other zeaxanthin and capsanthin compounds, concentration in the second year (2019) was found to be significantly lower when compared to the first year (2018).

Based on findings in this study, capsanthin was higher in 0% but did not change in 50%. However, in 100%, a decline in concentration was evident. The concentration of Zeax DE was found to be higher in HET and under detection limit in UNIK and HAB. Beta-carotene was higher in HET (74.42±20.85 µg/g), UNIK (84.86±23.92 µg/g), and UNIJ (58.41±13.8 µg/g) but in significantly lower concentration in HAB (0.07±0.02 µg/g). A decline in β-carotene concentration was observed in the second growing season (HET, 30.32±11.33 µg/g; UNIK, 13.58±2.77 µg/g; UNIJ, 18.0±7.12 µg/g and HAB, 0.86±0.79 µg/g). A decrease in β-carotene in the second growing season may be a result of decreased precipitation and irrigation or water supply treatment. Total carotenoid concentrations were found to be higher in HET, UNIK, and UNIJ during the third harvest (0%) and decreased in HAB. Irrespective of the cultivar and harvesting periods, a higher concentration of total carotenoids was found in 0% and 50%.

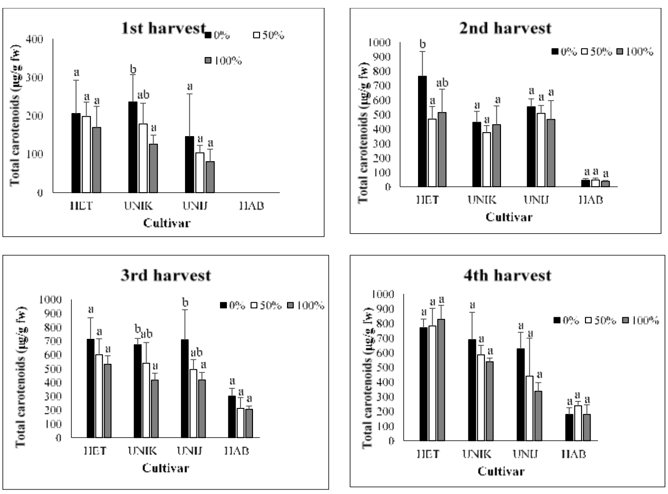


Figure 2. Mean concentration of total carotenoids present in the chilli pepper cultivars at the various harvesting stages in the 2019 growing season.

Based on the effect of irradiation application on phytochemicals, the various doses were used; 0.5 kGy and 5.0 kGy at different ripening stages in 2018 and 2.5 kGy, 7.5 kGy, and 10 kGy in 2019. In both studies, 0 kGy was used as control. Irradiation dose decreased in both major capsaicinoids concentration (CAP and DC) and homologue compounds (NDC, iDC, and HDCs) in HET red at a dose rate of 5.0 kGy, in both major capsaicinoids concentration (CAP and DC) and homologue compounds in HET red at a dose rate of 0.5 kGy, and at 5.0 kGy in HET brick-red. At 0 kGy, CAP and DC concentration were high in UNIJ brick red (36400.0±0.00 µg/g), HET brick-red (2765.0±0.00 µg/g) and UNIK brick-red (1120.0±0.00 µg/g) when compared to UNIJ red (32025.0±0.00 µg/g), HET red (1890.0±0.00 µg/g) and UNIK red (658.0±0.00 µg/g) respectively. The various doses (2.5 kGy, 7.5 kGy, and 10 kGy) had a significant effect ($p<0.05$) on NDC, DC, HCAP, iDC, and HDCs. CAP levels were not altered after irradiation, even though a slight increase in pungency was found in UNIJ (14116.7 ± 1457.17 µg/g) at a dose rate of 10 kGy.

On tocopherols in the previous year, the major tocopherol concentration (γ-toc, β-toc, and α-toc) were not affected by low dose irradiation in HET red, UNIK red, and UNIJ red. However, the minor tocopherol concentration (γ-toc ester, β-toc ester, and α-toc ester) in HET brick-red, UNIK brick-red, and UNIJ brick-red were not stable in the entire study. A decrease and increase in tocopherol concentration, mostly minor compounds, were reported in this study. It revealed in this study that HET brick-red had a decreased α-toc concentration at 5.0 kGy, an increase at 0.5 kGy in UNIK brick-red, and a decrease at 0.5 kGy in UNIJ brick-red. The concentration of γ-toc in HET brick-red was not significantly different from UNIK brick-red and UNIK brick-red. Generally, irradiation did not influence tocopherol concentration HET, UNIK, and UNIJ. However, at a dose rate of 2.5 kGy, UNIJ had reduced α-toc quinone concentration but was not in the case on HET and UNIK. A decline in α-toc quinone and γ-toc ester concentration as the irradiation dose increased was found in UNIJ.

On carotenoids, the effect of irradiation application on carotenoids concentration in different chilli peppers is shown in Table 3.

Table 3. Change in content (µg/g) of the main carotenoid groups as a function of irradiation dose in the year 2019. The means are expressed in ± S.D (n = 4) based on dried weight.

Carotenoid group	**Irradiation dose**			
	0kGy	**2.5kGy**	**7.5kGy**	**10kGy**
		HET		
Free Yellow Xanthophylls	147.8±9.3a	175.2±5.9b	142.0±5.8c	123.8±10.0a
Yellow MEs	299.3±31.3a	423.6±62.0b	396.9±25.6b	345.3±58.3b
Yellow DEs	101.5±6.8a	164.2±8.2b	141.6±8.9c	106.2±3.9a
Total esterified Yellow	400.8±38.1a	587.8±70.2b	538.5±34.5b	451.6±62.2a
Esterified/Free Yellow	2.7±0.2a	3.6±0.07b	3.8±0.2b	3.7±0.38b
Total Yellow xanthophylls	707.4±60.3a	1014.4±79.0b	984.2±34.7b	712.2±153.9a
Unesterified Red	160.9±11.9a	154.8±8.7a	115.6±10.0b	111.8±15.2b
Red MEs	511.9±32.4a	633.0±21.2b	548.2±51.1a	474.4±27.9a
Red DEs	1316.9±118.1a	1693.2±104.2b	1441.2±132.5a	1118.8±43.0c
Total esterified red	1477.8±150.5a	2326.2±125.4b	1989.4±217.3a	1593.6±70.9a
Esterified/Free Red	9.18±0.81a	15.0±1.8b	17.21±1.7b	14.3±1.3c
Total Red xanthophylls	1984.6±148.3a	2497.3±117.2b	2137.9±221.9b	1720.2±74.3a
β-carotene	156.7±17.9a	251.5±39.7b	303.7±46.1b	190.0±26.7a
Total Zeaxanthin	112.4±4.8a	179.6±8.2b	116.4±18.5a	115.7±13.0a
Total Carotenoids	2692.1±208.3a	3511.8±165.2b	3122.1±188.2b	2432.4±155.8a
Red/yellow	2.80±0.04a	2.47±0.18b	2.17±0.30b	2.50±0.57b
		UNIK		
Free Yellow xanthophylls	160.0±12.2a	138.3±11.9b	134.9±11.0b	139.7±8.2b
Yellow MEs	551.1±33.7a	500.5±27.4a	423.2±34.9b	426.8±36.9b
Yellow DEs	65.0±5.5a	78.7±2.2b	72.9±6.3b	81.1±7.3b
Total esterified Yellow	616.1±39.3a	579.2±29.6a	496.1±41.2b	507.9±44.2b
Esterified/Free Yellow	3.8±0.27a	4.2±0.34a	3.7±0.33a	3.6±0.27a
Total Yellow xanthophylls	776.2±28.5a	707.2±25.9b	634.8±67.6b	682.6±59.4b
Free Red Xanthophylls	249.3±4.6a	205.8±11.4b	217.0±22.9b	211.2±4.7b
Red MEs	333.2±24.6a	308.3±9.1a	316.2±24.5a	254.0±29.7b
Red DEs	1041.5±79.4a	982.9±61.4a	998.3±98.7a	859.8±88.4a
Total esterified red	1374.7±103.9a	1291.2±70.5a	1314.5±123.2a	1113.8±118.1a
Esterified/Free Red	5.5±0.28a	6.3±0.50a	6.1±0.60a	5.3±0.32a
Total Red xanthophylls	1624.1±103.1a	1496.9±25.3a	1525.71±121.0a	1343.6±120.9a
β-carotene	211.4±13.6a	258.3±8.8b	189.3±32.3a	231.2±12.6a
Total Zeaxanthin	257.0±18.9a	336.8±36.6b	294.9±15.6b	206.3±11.6c
Total Carotenoids	4024.4±229.4a	3711.4±304.4a	3734.03±301.2a	3396.0±260.6a
Red/yellow	2.09±0.08a	2.05±0.09a	2.40±0.12b	1.96±0.07a
		UNIJ		
Free Yellow xanthophylls	263.4±23.4a	247.2±28.5a	211.8±23.0a	134.0±10.1b
Yellow MEs	406.1±29.4a	408.4±24.4a	368.3±3.0b	235.2±16.0c
Yellow DEs	197.8±31.0a	278.9±5.2b	275.8±27.4b	197.2±20.9a
Total esterified Yellow	603.9±60.4a	687.3±29.6a	644.1±30.4a	432.4±36.9b
Esterified/Free Yellow	2.3±0.21a	2.8±0.22b	3.0±0.23b	3.2±0.24b
Total Yellow Xanthophylls	1231.3±81.1a	1389.8±29.8b	1280.3±27.0a	819.7±41.5c
Free Red xanthophylls	436.7±37.9a	345.1±24.6b	216.9±381.9c	134.3±34.9d
Red MEs	659.9±83.9a	750.9±55.2b	604.4±55.4a	397.3±9.1c
Red DEs	1314.1±115.6a	1508.3±59.8b	1371.0±50.8a	975.9±90.8c
Total esterified red	1974.0±199.5a	2259.2±115.0b	1975.4±106.2a	1373.2±99.8c
Esterified/Free Red	4.5±0.45a	6.5±0.40b	9.1±1.0c	10.2±1.6c
Total Red xanthophylls	2410.7±129.2a	2604.4±93.3a	2192.4±112.7a	1507.5±47.9b
β-carotene	349.0±22.4a	442.6±41.4b	421.1±37.1b	255.1±13.9c
Total Zeaxanthin	138.4±19.2a	148.4±11.1a	133.0±15.2a	150.5±14.1a
Total Carotenoids	3641.9±209.4a	3875.3±107.7a	3472.6±124.1a	2327.2±88.1b
Red/yellow	1.96±0.08a	1.88±0.06a	1.71±0.08b	1.84±0.04a

4.0 CONCLUSIONS AND RECOMMENDATIONS

Water supply to plants is a necessary component that contributes to crop growth and yield. Deficit irrigation may be beneficial in areas with water scarcity or shortage. As focused on this study, a continuous harvest of peppers is encouraged, but deficit irrigation should be discontinued under open field environments as the weather conditions change to low temperatures. Maintaining a no irrigation programme (0% water except natural precipitation and fertigation) around these periods would produce high yields in chilli peppers, vitamin C, increase capsaicin in Hetényi Parázs' (HET) and α-tocopherol concentration in 'Hetényi Parázs' (HET) and 'Unikal' (UNIK). Tocopherols decreased as precipitation and irrigation decreased. However, 'Unijol' (UNIJ) may be cultivated for tocopherols (vitamin E) under deficit irrigation and 0% water for yields. Habanero (HAB) under 0% or control under low temperature would be suitable for yield or marketability.

Based on our findings on pungency stability under low irrigation application, UNIJ (Unijol) hybrid pepper and HAB (Habanero) are recommended for consumer preference and pharmacological purposes. Since water stress and optimum water supply may influence poor fruit setting and low yield, HET (Hetényi Parázs) and UNIK (Unikal) hybrid peppers are suitable marketable yield and consumer preference.

It is further recommended for future studies into the phytochemical response of these pepper cultivars to water supply treatment under modified atmosphere or greenhouses.

5.0 NEW SCIENTIFIC RESULTS

1. I found out that at water deficiency of 50% increased significantly the yield of all chilli pepper cultivar studied, while the optimal water supply decreased the yield up to 52% for Habanero, 5% for 'Unikal', 7% for 'Hetényi Parázs' and 14% for ‘Unijol’;

2. Less water supply increased pungency in 'Hetényi Parázs' and 'Unikal', but more water slightly increased capsaicin in ‘Unijol’ and ‘Habanero’ which are initially very pungent peppers;
3. Also, it was proven that the concentration of tocopherols and carotenoids decreases as accumulated precipitation and irrigation decrease.
4. With Gamma irradiation at the beginning of the over-ripening of the new chilli cultivars, a novel technology was achieved to improve the quality and safety attributes of the spice chilli crop. The novel technology development resulted in some new approaches:
    a. The application of Ɣ-irradiation at 2.5 kGy doses improved the concentration of health promotive phytonutrients significantly, thereby increasing the nutritive value and stability of chilli pepper products,
    b. The 10 kGy dose, which is effective in detoxification via retarding the microbial growth, caused degradation to carotenoids and capsaicinoids, but not to a great extent. The maximum loss of 32% for carotenoids and 38% for minor capsaicinoids in the ‘Unijol’ cultivar, while slight degradation occurred in 'Hetényi Parázs' and ‘Unikal’.

6.0 PUBLICATIONS

Journals with Impact Factor

1. Agyemang Duah, S., Silva e Souza, C., Daood, H. G., Pék, Z., Neményi, A., & Helyes, L. (2021). Content and response to Ɣ-irradiation before over-ripening of capsaicinoid, carotenoid, and tocopherol in new hybrids of spice chili peppers. LWT, 111555. https://doi.org/https://doi.org/10.1016/j.lwt.2021.111555
2. Agyemang Duah, S.; Souza, C.S.e; Nagy, Z.; Pék, Z.; Neményi, A.; Daood, H.G.; Vinogradov, S., & Helyes, L. (2021). Effect of Water Supply on Physiological Response and Phytonutrient Composition of Chili Peppers. Water 2021, 13, 1284. https://doi.org/10.3390/w13091284
3. Andryei, B., Horváth, K.Z., Agyemang Duah, S., Takács, S., Égei, M., Szuvandzsiev, P., Neményi, A. (2020). Use of plant growth promoting rhizobacteria (PGPRs) in the

mitigation of water deficiency of tomato plants (Solanum lycopersicum L.). Journal of Central European Agriculture, 2021, 22(1), p.167-177 DOI: /10.5513/JCEA01/22.1.3036

Journals without Impact Factor

1. Agyemang Duah, S., Nagy, Z., Silva e Souza, C., Pék, Z., Neményi, A., & Helyes, L. (2021). Effect of net shading technology on the yield quality and quantity of chilli pepper under greenhouse cultivation. Acta Agraria Debreceniensis DOI: 10.34101/actaagrar/1/8348 ***(In press paper)***
2. Silva e Souza, C., Agyemang Duah, S., Neményi, A., Pék, Z., & Helyes, L. (2020). The impact of cultivar and irrigation on yield, leaf surface temperature and SPAD readings of chili pepper. Acta Agraria Debreceniensis, (2), 103–108. https://doi.org/10.34101/ACTAAGRAR/2/4286
3. Agyemang Duah, S., Nagy, Z., & Helyes, L. (2019). The effect of different shading net on the Quantum Efficiency of PS II in chilli pepper cultivar 'Star Flame'. Acta Agraria Debreceniensis, (2), 21–23. https://doi.org/10.34101/actaagrar/2/3673
4. Adiyah Fowzia, Agyemang Duah Stella, Fuchs Marta. (2018). Evaluation of some selected soil parameters influencing water management of different types of soils in Ghana: A case study in Ashanti Region. In: Jakab, Gusztáv; Tóth, Attiláné; Csengeri, Erzsébet (eds.) Adaptive Water Management: Opportunities and Risks. International Conference on Water Science Szarvas, Hungary: Szent István University, Faculty of Agriculture and Economics (2018) 326 p. pp. 211-217., 7 p.
5. Duah, S. A., Emi-Reynolds, G., Kumah, P., & Larbi, D. A. (2018). Effect of gamma irradiation on the microbiological quality and shelf life of Engraulis encrasicolus in Ghana. International Journal of Fisheries and Aquaculture, 10(3), 16-21. https://doi.org/10.5897/IJFA2017.0656