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Effect of Different Production Systems on Chemical Profiles of Dwarf French Bean (*Phaseolus vulgaris* L. cv. Top Crop) Pods

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ABSTRACT: The chemical composition of dwarf French bean (*Phaseolus vulgaris* L.) cv. Top Crop was compared among five production systems: conventional, integrated, organic, and biodynamic production systems and the control. Determination of sugars and organic acids was performed with a HPLC system, and identification of individual phenolic compounds using HPLC-MS. The chemical composition of the beans was unaffected by the production systems; however, the content levels of individual compounds were changed. The pods from integrated production contained the lowest levels of glucose and sucrose and the highest levels of catechin, procyanidin dimers, and a vanillic acid derivative. The control treatment, as well as organic and biodynamic productions, positively affected the levels of sugar content and caused a lower content of catechin and *trans-p*-coumaroylaldaric acids. Beans from the conventional production system contained the lowest levels of fructose, glucose, ascorbic acid, and many phenolics from various groups.

KEYWORDS: *conventional, integrated, organic, biodynamic, production system, sugars, organic acids, phenolics, beans*

INTRODUCTION

Fruit and vegetable production represents an important proportional share within agriculture and is in recent years increasingly influenced by specific consumers' demands, environment protection regulations, and the economic pressure of the producers. The conventional production system, generally striving to increase yields, uses mineral fertilizers according to good agricultural practice and crop nutrient uptake estimates. The use of herbicides and pesticides is preventive and also applied according to good agricultural practices, and harrowing is performed only when needed.[1] Because the application of mineral fertilizers and pesticides is frequently higher than necessary in conventional farming, this farming system is environmentally questionable, and therefore integrated production was developed in the middle of the 20th century. Integrated production includes at least one harrowing during the season and is characterized by a controlled use of mineral fertilizers on the basis of soil analysis and nutrient uptake estimates and the use of herbicides and pesticides according to the prognosis, observations, and the rules of integrated farming management.[1,2]

Subsequent technological progress at the end of the previous century led to advances in organic production. In this system harrowing is performed twice to up to five times per season, and cover crops after cereals are sown to ameliorate soil characteristics. Synthetic pesticides and fertilizers, plant growth regulators, and genetically modified organisms[3] are excluded from organic production. Pest management in organic vegetable production includes the use of some approved natural pesticides when necessary and a limited input of cattle manure per hectare according to the rules of organic production.[1,3] Biodynamic agriculture is one of the more advanced organic agricultural farming methods, in which nine different preparations to aid fertilization are used.[4] It promotes diversified, resilient, and ever-evolving farms, which provide ecological, economical, and physical long-term sustainability for humankind.[5]

Many studies have compared the quality of fruit and vegetables from two production systems, mainly organic and conventional.[6−9] Others have also compared integrated and organic production.[10,11] Heimler et al.[12] compared differences in polyphenol content and antioxidant activity of lettuce among three farming systems. It is hard to compare several production systems in one study mainly because farms with different production practices are rarely close together and a great variety of environmental factors, soil properties, production systems, and sampling methods all influence the composition of fruit and vegetables.[1]

The studies analyzing vegetables from different production systems have mainly focused on cabbage, carrots, tomatoes,[13] lettuce,[12,14] and spinach.[9] Other vegetable crops, such as dwarf French bean, have been examined to a lesser extent. Dwarf French bean is valued as a rich source of folic acid, vitamin B_6, minerals, carotenoids, carbohydrates, and various bioactive compounds.[15] Nowadays, the content of phytochemicals in different fruit and vegetables is a topic of great interest in food science, as they play a critical role in human health and may be nutritionally important.[16]

In our study the chemical composition of dwarf French bean grown under five different production systems (conventional, integrated, organic, and biodynamic systems and the control)

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Table 1. Plant Protection and Fertilizer Applications for Dwarf French Bean (*Phaseolus vulgaris* L.) Production in the Year 2011

production system	weed protection	plant protection applied	fertilizer applications	amounts of nutrient applied (kg/ha) N	%[b] N	P	% P	K	% K
conventional		(June 1)							
	manual (July 21)	Basagran 600 (1.5 L/ha), herbicide	NPK fertilizer 7−20−30 (200 kg/ha)	14	100	40	100	60	100
		Agil 100 EC (2 L/ha), herbicide							
integrated	*mechanical (May 24)*	Basagran 600 (1 L/ha), herbicide	NPK fertilizer 7−20−30 (200 kg/ha)	14	100	40	100	60	100
	manual (July 21)	Agil 100 EC (1.5 L/ha), herbicide							
organic	mechanical (May 24)		cattle manure[a] (20 000 kg/ha)	35	250	33	83	151	252
	manual (June 2)								
	manual (July 21)								
biodynamic	mechanical (May 24)		composted cattle manure with biodynamic preparations[a] (20 000 kg/ha)	35	250	63	158	50	83
	manual (June 2)								
	manual (July 21)								
control	mechanical (May 24)			0	0	0	0	0	0
	manual (June 2)								
	manual (July 21)								

[a]Cattle manure and composted cattle manure were analyzed for their NPK contents before application and in the case of N availability of N for plants in the first year was estimated on 35 kg/ha in both cases. [b]% of supply regarding conventional production.

has been compared. For this purpose adjoining plots with similar micropedoclimatic conditions were managed according to different technological principles. To our knowledge this is the first report presenting the biochemical differences in the levels of primary and secondary metabolites in bean produced according to five different systems.

■ MATERIALS AND METHODS

Plant Material and Growing Conditions. Dwarf French bean (*Phaseolus vulgaris* L.) cv. Top Crop was grown in 2011 in a long-term field trial at the University Agricultural Centre of University of Maribor in Pivola near Hoče (46°28′ N, 15°38′ E, 282 m a.s.l.), Slovenia. Twenty plots (2.4 × 7 m) were randomly assigned to the five production systems in four replications per system until the year 2007, when the trial started. Seeds were sown directly on the experimental plots on the same day (May 11, 2011); the planting density was 0.6 m × 0.05 m. Top crop organic seeds were not available for the most important cultivar in the region, and therefore untreated conventional seeds were used for the experimental study. The farming systems mostly differed in plant protection and fertilization strategies: conventional farming according to the Slovene agriculture act and good agricultural practice, integrated farming according to Slovene standards for integrated farming, organic farming according to the European Commission Regulation on Organic Farming, and biodynamic farming according to Demeter International Production Standards and European Commission Regulation on Organic Farming.[1] In the control treatment no fertilization or plant protection was used. Experimental field plots were established on a dystric cambisol (deep) (average pH value 5.5 in 0.1 KCl solution, soil soluble P of 0.278 g/kg and soil soluble K of 0.255 g/kg in top soil layer). Nitrogen fertilization was done based on N_{min} value in the soil profile (0−0.9 m) in the middle of April 2011. In organic and biodynamic plots 27 kg N min/ha was incorporated in the soil, and in conventional and integrated plots 46 kg N_{min}/ha was applied. The applied measures as well as the fertilization and plant protection plan for an individual production system are presented in Table 1.

Pods from each plot were hand-picked separately to demonstrate the uniformity within each production system. Pods were counted and weighed. Additionally, dry matter was measured at 105 °C for 24 h. The content among treatments was as follows: control (16%) > integrated ≈ organic ≈ biodynamic (14%) > conventional (13%). Crop load did not differ between the production systems (15−16 kg per plot) except in the control treatment, where a lower yield was measured (10 kg per plot). For chemical assessment, 10 pods from each plot were harvested on July 26, 2011, at beginning seed stage and stored at −20 °C until the analyses.

Analysis of Individual Sugars and Organic Acids. The middle parts of pods of dwarf French bean cv. Top Crop were analyzed for carbohydrates (sucrose, glucose, and fructose) and organic acids (malic and citric acid). Extraction was carried out according to the method described by Jakopic et al.[17] In the laboratory, 10 g of the fresh mass was immersed in 50 mL of bidistilled water and homogenized with a T-25 Ultra-Turrax (Ika-Labortechnik). For the analysis of ascorbic acid pods were cut into small pieces using a ceramic knife, and 2.5 g was extracted with 5 mL of 2% *m*-phosphoric acid as described by Bizjak et al.[18]

Samples were left for extraction for half an hour at room temperature, with frequent stirring, and were centrifuged for 7 min at 10 000 rpm (Eppendorf Centrifuge 5810R) afterward. The supernatant was filtered through a 0.45 μm cellulose mixed esters filter (Macherey-Nagel; Düren, Germany), poured into a vial, and analyzed using a high-performance liquid chromatography (HPLC; Thermo Scientific, Finnigan Spectra System, Waltham, MA, USA) system. Analyses of primary metabolites on HPLC were carried out according to the previously described methods[17] with some modification. For each analysis of sugars and organic acids, 20 μL of sample was used. A Phenomenex Rezex RCM-monosaccharide column with a flow of 0.6 mL/min operating at 65 °C was used for the analysis of sugars. For the mobile phase, bidistilled water and a RI detector for identification were used. Organic acids were analyzed with a Phenomenex Rezex ROA-organic acid column with a flow of 0.6 mL/min and 4 mM sulfuric acid (H_2SO_4) for the mobile phase. Malic and citric acid were analyzed at 65 °C, and a 210 nm wavelength UV detector was used for identification. A similar method to that for malic and citric acid was used for the quantification of ascorbic acid with the exception of temperature and wavelength. The latter was identified on a 245 nm wavelength UV detector at room temperature. The identification and quantification of carbohydrates, organic acids, and ascorbic acid were achieved with comparison of the retention times and concentrations of the corresponding external standards.

Analysis of Individual Phenolics. For the analyses of individual phenolics, middle parts of pods were cut into small pieces, and 5 g of sample was extracted with 25 mL of methanol containing 1% (w/v)

Table 2. Content of Individual Sugars (mg/g DW) in Dwarf French Bean in Different Production Systems[a]

production system	fructose	glucose	sucrose	sum of sugars
biodynamic	4.53 ± 0.10 b,c	3.57 ± 0.08 b	0.50 ± 0.04 a,b	8.61 ± 0.21 b,c
organic	4.58 ± 0.11 b,c	3.66 ± 0.11 b	0.53 ± 0.02 b	8.77 ± 0.22 c
integrated	4.26 ± 0.20 a,b	3.16 ± 0.03 a	0.39 ± 0.05 a	7.80 ± 0.18 a,b
control	4.93 ± 0.23 c	3.86 ± 0.20 b	0.58 ± 0.06 b	9.37 ± 0.48 c
conventional	3.88 ± 0.16 a	3.16 ± 0.13 a	0.45 ± 0.02 a,b	7.49 ± 0.29 a

[a]Average values ± SE are present ($n = 5$). Different letters in a column present statistically significant differences among production systems (Duncan's multiple-range test; $p < 0.05$.

2,6-di-*tert*-butyl-4-methylphenol (BHT) in an ultrasonic bath for an hour. After extraction, the treated samples were centrifuged for 10 min at 10 000 rpm. The supernatant was filtered through a 0.45 μm Chromafil AO-45/25 polyamide filter (Macherey-Nagel, Düren, Germany) and transferred into a vial prior to injection to the HPLC system.

Extracts were analyzed using a Thermo Finningan Surveyor HPLC system (Thermo Scientific, San Jose, CA, USA) with a diode array detector at 280 nm (flavan-3-ols, vanillic acid derivative, *p*-coumaroylaldaric acids) and 350 nm (quercetin and kaempferol derivatives). A Phenomenex HPLC C_{18} column (150 × 4.6 mm, Gemini 3u) protected with a Phenomenex security guard column operating at 25 °C was used. The injection volume was 20 μL and the flow rate, 1 mL/min. Elution solvents were aqueous 1% (v/v) formic acid with 5% acetonitrile (A) and pure acetonitrile (B). Samples were eluted according to the gradient described by Marks et al.[19]

The phenolic compounds were identified by comparing their UV—vis spectra from 220 to 550 nm and retention times and further confirmed using a mass spectrometer (Thermo Scientific, LCQ Deca XP MAX) with an electrospray interface (ESI) operating in negative ion mode. The analysis was carried out using full-scan data-dependent MS^2 scanning from m/z 115 to 1000. Quantification was achieved according to the concentrations of a corresponding external standard and was expressed as mg/kg dry weight (DW) of pods. Procyanidin dimers are presented in equivalents of procyanidin B1, *trans-p*-coumaroylquinnic acids in equivalents of *p*-coumaroyl acid, vanillic acid derivatives in equivalents of vanillic acid, quercetin glycosides in equivalents of quercetin 3-*O*-rutinoside, and kaempferol derivatives in equivalents of kaempferol 3-*O*-glucoside.

Chemicals. The following standards were used to determine the chemical compounds in pods: sucrose, fructose, glucose, malic and citric acid, kaempferol 3-*O*-glucoside, vanillic acid, *p*-coumaric acid, and procyanidin B1 from Fluka Chemie GmbH (Buchs, Switzerland), quercetin 3-*O*-rutinoside and ascorbic acid from Sigma-Aldrich Chemie GmbH (Steinheim, Germany), and (+)-catechin from Roth (Karlsruhe, Germany).

The chemicals for the mobile phases were acetonitrile and formic acid from Fluka Chemie GmbH (Buchs, Switzerland). The water used in sample preparation, solutions, and analyses was bidistilled and purified with a Milli-Q water purification system by Millipore (Bedford, MA, USA).

Statistical Evaluation. The results were statistically analyzed with the Statgraphics Plus program for Windows 4.0, using one-way analysis of variance (ANOVA). The differences in the content levels were estimated with Ducan's test. *p*-Values of < 0.05 were considered statistically significant. Multivariate statistical analysis (hierarchical cluster analysis, discriminate analysis, and classification) was conducted to interpret the differences in all analyzed compounds among different production systems. Ward's method based on square Euclidean distance was used to interpret the differences in primary and secondary metabolites of different production systems of dwarf French bean.

RESULTS AND DISCUSSION

Sugars. Fructose was the main analyzed sugar in dwarf French bean pods and ranged from 3.88 in convetional production up to 4.93 mg/g DW in the control treatment (Table 2). Fructose represented from 52% to 54% total analyzed sugars, which is in accordance with the findings of Sanchez-Mata et al.,[20] who reported fructose as the major sugar (47.8% total soluble sugars) in dwarf French beans. In our study, a considerable part was represented by glucose (42%), while sucrose was measured only in small amounts (no more than 6% of total analyzed sugars).

Beans cultivated according to conventional, integrated, organic, and biodynamic practices and the control treatment contained different levels of all individual sugars and, consequently, total analyzed sugars (Table 2). Content levels of fructose were lowest in the conventional treatment. In the integrated treatment values were higher but not significantly, while statistically higher contents were determined in organic and biodynamic treatments, and the highest fructose content was found in the control. Content levels of glucose were lower in integrated and conventional treatments in comparison with the other three production systems. In integrated production, the lowest sucrose content was also observed, while the highest sucrose content was determined in pods cultivated according to the organic system and in control treatment. In a study of Bavec et al.,[1] investigating the effect of different production systems on red beet, no significant differences in the content levels of sugars have been reported, although more total sugars were measured in organic systems. Rembialkowska[21] reported that different studies clearly indicate a higher content of total sugars, mainly sucrose, in organically produced vegetables such as carrots, sugar beet, red beetroot, spinach, and Savoy cabbage. Similarly, dwarf French bean pods from organic and biodynamic production as well as the control contained higher levels of total sugars in comparison with pods cultivated according to integrated and conventional practices.

Organic Acids. The most abundant organic acid in dwarf French bean pods was malic acid (representing more than 90%) followed by citric acid (Table 3). Minor organic acids such as tartaric and fumaric acid were also identified in bean pods, but their concentrations were several fold lower or were detected only in traces. No statistically significant differences in the content levels of minor organic acids were measured among different production systems.

Table 3. Content of Individual Organic Acids (mg/kg DW) in Dwarf French Bean in Different Production Systems[a]

production system	malic acid	citric acid	ascorbic acid
biodynamic	642 ± 26	50.5 ± 5.0	18.2 ± 0.6 b
organic	670 ± 48	60.2 ± 7.2	19.9 ± 0.8 b
integrated	656 ± 31	54.2 ± 4.3	17.7 ± 1.6 b
control	687 ± 21	63.7 ± 7.8	17.7 ± 1.8 b
conventional	575 ± 38	43.3 ± 4.8	8.9 ± 1.0 a

[a]Average values ± SE are present ($n = 5$). Different letters in a column present statistically significant differences among production systems (Duncan's multiple-range test; $p < 0.05$).

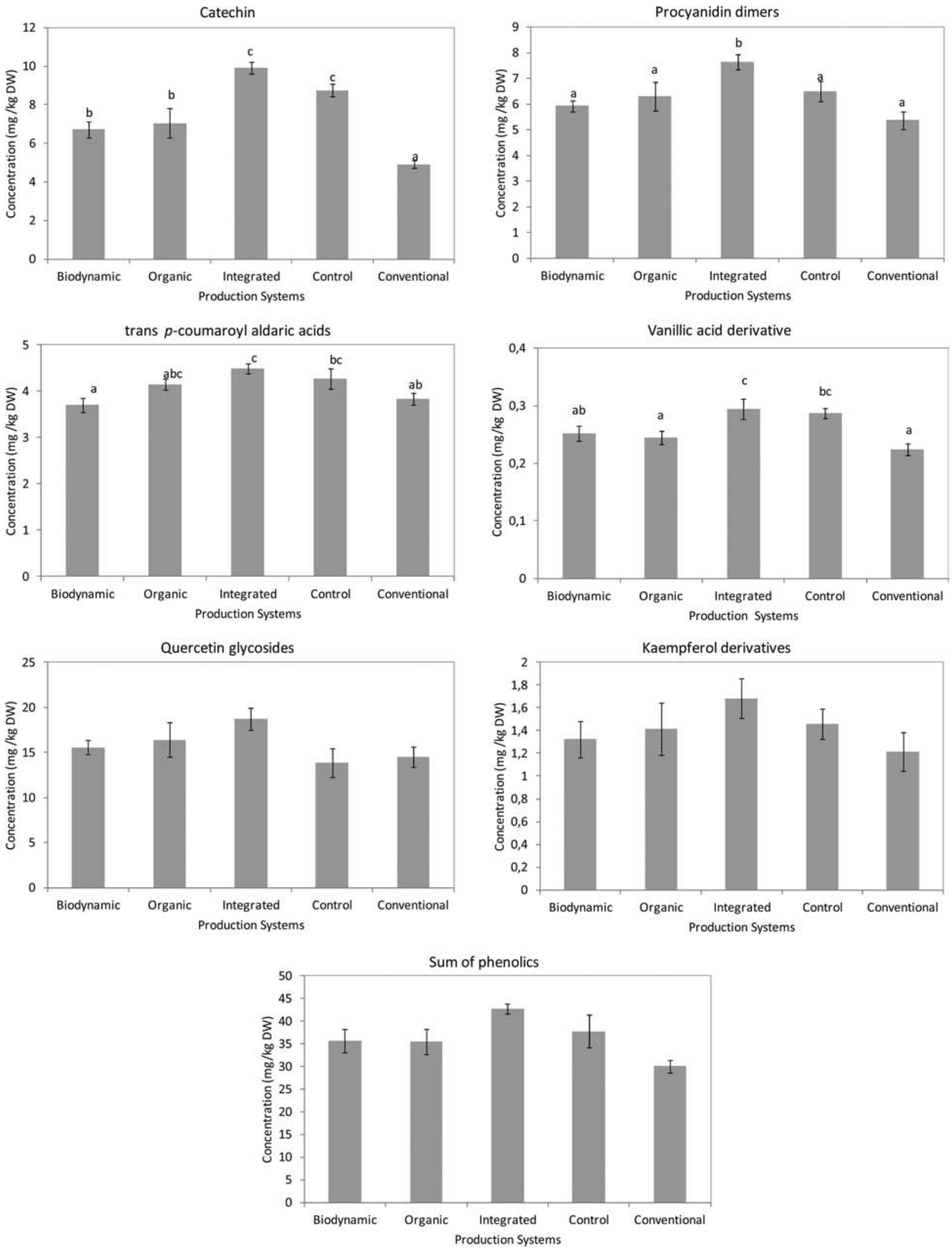

Figure 1. Content levels of individual phenolic compounds (mg/kg DW) in dwarf French bean from five production systems. Average values and standard error bars are presented ($n = 5$). Different letters indicate statistically significant differences in the content levels of phenolics in different production systems at $p < 0.05$.

Although no statistically significant differences in the content of malic and citric acid were observed among the investigated systems, dwarf French bean pods from conventional production contained lower levels of the analyzed acids in comparison with the other systems. Similarly in a study on red beet the fruit from the control treatment contained higher concentrations of malic acid compared to the conventional production.[1] However, in the case of red beet similar differences were not confirmed for citric, fumaric, and shikimic acid. Moreover, several studies investigating the influence of different production systems on various vegetable species do not report a uniform effect on the content levels of malic, citric, or oxalic acid and total organic acids.[7]

In the dwarf French bean pods the prevailing part of vitamin C is represented by ascorbic acid in the range 66−100%.[22,23] In our study, the content level of ascorbic acid ranged from 8.9 mg/kg DW in the conventionally produced bean pods to 19.9 mg/kg DW in the organically grown beans. It is in the range 50−175 mg/kg FW, previously reported[23−25] in raw French bean pods.

In conventional production the amount of ascorbic acid was significantly lower in comparison to other analyzed production systems. Although it is difficult to reach general statements on the effect of production systems on the levels of individual bioactive compounds, several studies on vegetables and fruit report a similar tendency of higher vitamin C levels in organically grown crops.[7,9] Hallmann[26] reported that the vitamin C content in tomato fruits depended significantly on the level and type of fertilization. In their opinion, higher amounts of vitamin C in the organic production in comparison to conventional could be linked with the form of nitrogen, while the nitrate form (NO_3^-) could influence higher vitamin C content in fruit than ammonium nitrogen (NH_4^+).

Phenolic Compounds. Phenolic compounds are important constituents of vegetables, determining their appearance, flavor, taste, and color.[27] Additionally, the level of phenolics in fruit and vegetables considerably affects the consumer's preferences due to their noted beneficial health properties. Namely, phenolics are distinguished by a wide spectrum of positive chemical properties that potentially help prevent the development of several diseases such as cancer and cardiovascular disorders.[27]

The influence of conventional, integrated, organic, and biodynamic production systems and the control on the content levels of individual phenolics was studied in dwarf French bean pods (Figure 1). Sixteen individual phenolic compounds from four groups were determined. Different production systems caused changes only in the content levels of some phenolic compounds and did not affect the general chemical composition of bean pods, as all individual phenolic compounds were detected in all treatments.

Flavonoids (flavan-3-ols and flavonols) were the prevailing phenolic group among the analyzed secondary metabolites in bean pods. Their sum ranged between 25.98 (conventional) and 37.94 mg/kg DW (integrated), which represents more than 91% of all analyzed phenolics (Figure 1). The most abundant group of phenolics was the group of flavonols, in which three quercetin glycosides and two kaempferol derivatives were identified. Quercetin glycosides (13.8−16.4 mg/kg DW) represented the main part, followed by kaempferol derivatives. Flavan-3-ols were the second most abundant phenolic group, in which catechin and three procyanidin dimers were identified. Jiratanan et al.[23] similarly analyzed total flavonoids in French beans and reported about 50 mg of catechin equivalents per 100 g of fresh tissue.

trans-p-Coumaroylaldaric acids were also detected in small amounts in addition to low content levels of a vanillic acid derivative.

Content levels of individual phenolics in the plants are greatly dependent on many factors. Specifically, light, temperature, growth regulators, tissue damage, pathogen attack, fungicide and herbicide application, and nutritional status of certain nutrients all affect the phenolic content.[6,28−30] In addition, the type of production system also influenced the phenolic content in the pods of dwarf French bean in our study.

In bean pods cultivated according to integrated production practices the highest levels of individual phenolics such as flavan-3-ols, *trans-p*-coumaroylaldaric acids, and a vanillic acid derivative were measured in comparison with the other production systems (Figure 1). A similar trend was observed for quercetin glycosides and kaempferol derivatives, although differences among treatments were not statistically significant. Between the organic and biodynamic farming system (a type of organic system) no significant differences in phenolic content levels were detected. The conventional production system differed mostly in the content of catechin; levels were significantly lower in comparison to other systems.

Organic farming tends to increase environmental stress and therefore intensifies the synthesis of polyphenols.[14] A 10-year study on tomato determined a higher flavonoid content in organic fruit in comparison with conventionally produced tomatoes.[13] Heimler et al.[12] reported significantly lower anthocyanin and polyphenol content levels in lettuce from conventional production compared to the biodynamic production system. Moreover, the level of polyphenols in biodynamically cultivated lettuce was approximately 36% higher than in conventionally grown product. Although a general opinion exists that organically produced fruit and vegetables contain higher levels of phenolic compounds that are synthesized as a response to higher stress pressure such as pathogen and pest attack,[10] there are many research studies that do not confirm this. Young et al.[14] even reported no differences in individual and total phenolic levels in leaf lettuce and collards between organic and conventional cultivation. Similarly, no differences in polyphenol content were confirmed in *Cichorium intybus*[31] cultivated according to conventional and biodynamic production.

Lower content levels of phenolic compounds were observed in the organic, biodynamic, and control treatment in comparison to the integrated treatment. The key enzyme in the metabolism of phenolic compounds is phenylalanine ammonia-lyase (PAL). Its activity was diminished at lower applications of nitrogen.[30] However, antagonistic effects between certain nutrients have been reported.[26,32]

The sum of all analyzed phenolics in dwarf French bean pods varied from 30.04 (conventional) to 42.73 (integrated) mg/kg DW. The values are comparable to those reported in a previous study,[22] where 221 mg of gallic acid equivalents per kg of fresh green beans has been measured. In our study, the sum of all analyzed phenolics did not differ statistically among the production systems. However, a tendency was observed among different production systems analyzed: similar amounts of phenolics were measured in the control, biodynamic, and organic systems, and the highest amounts were determined in the integrated system and the lowest in the conventional treatment. In a previous study,[1] total phenolic content differed among analyzed production systems in red beet. The authors report no differences among biodynamic, organic, and integrated production in the content levels of red beet phenolics. However, the contents of red beet phenolics in the

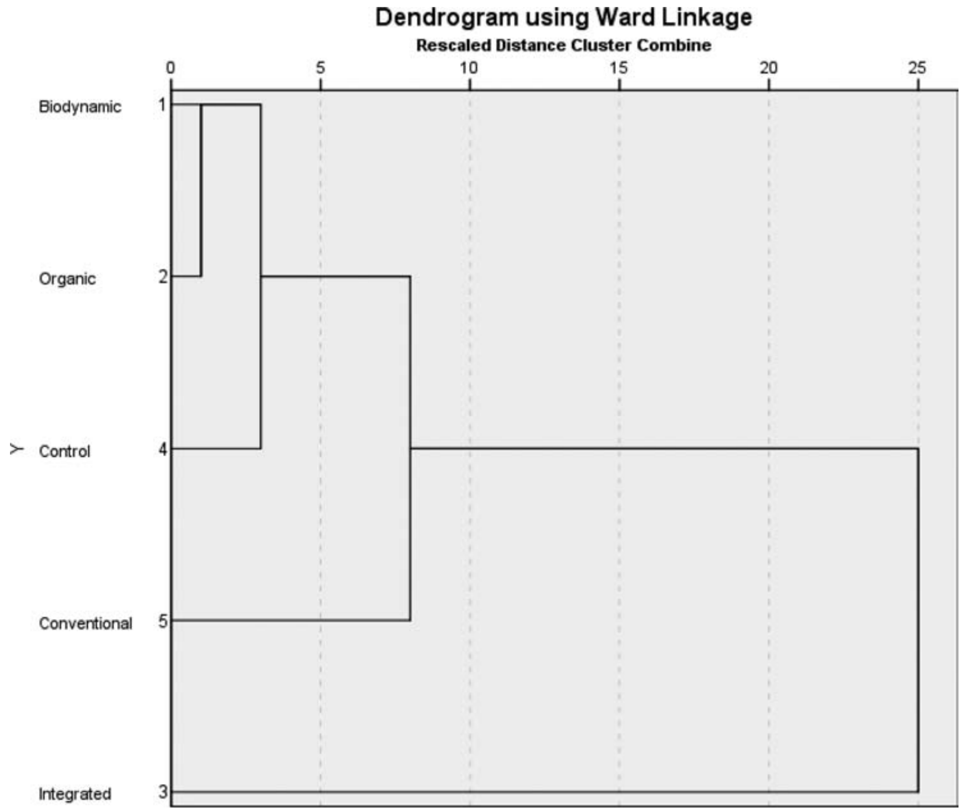

Figure 2. Dendrogram for analyzed primary and secondary metabolites of different production systems of dwarf French bean, using Ward's method based on square Euclidian distance.

control treatment were higher than in the conventional production systems, what is in agreement with our findings.

In many review articles where different production systems were compared[33−35] it was found that many studies were not totally correctly carried out. Often the farms included in the study were distant and the content levels of phytochemicals could be a consequence of different climatic conditions. The phytochemical content is influenced by many environmental factors, such as irrigation, temperature, light intensity, light spectrum, UV radiation, season, and location.[33,34] In our study, all these factors were comparable in all treatments. Differences were only in soil cultivation, pesticides, and nitrogen and other nutrients supplied. In organic and biodynamic systems, cattle manure was used in place of readily soluble mineral fertilizers to optimize soil biological activity. Zhao et al.[34] in a review article ascertained that plant secondary metabolism can be affected by fertilizers as well as by pesticides. They reported that a deficiency in nitrogen, phosphate, and iron may accumulate phenolics, while pesticides may either increase or decrease concentrations of phenolics in plants, depending on the mechanism of action of the pesticide. However, Poiroux-Gonord et al.[33] asserted that it is generally admitted that the carbon status influences the biosynthesis of vitamins and secondary metabolites, while precursor availability is essential for their biogenesis. They also reported that nitrogen did not affect the concentration of ascorbic acid and phenolic compounds in pepper nor the concentrations of quercetion and kaempferol in tomatoes.

Analogy among the Analyzed Production Systems. Similarities and discrepancies among the five production systems were determined using hierarchical cluster analysis (Figure 2). All investigated parameters (content levels of primary and secondary metabolites) were included in a combined cluster analysis, as a similar dendrogram was obtained in separate analyses of each metabolic group. As expected, the highest similarity was observed between the organic and biodynamic production systems. Namely, the latter derives from organic principles and includes sustainable application of organic fertilizers and a limited use of specifically permitted biological substances for pest and disease control. The control treatment also exhibited similarities to these two production systems and was therefore appointed to the first group. The group is characterized by moderate or low content levels of analyzed phenolic compounds and high contents of sugars and ascorbic acid. The similarity among these three production systems could be connected to lower nutrient supply to the plants and similar practices against pests and diseases.

Analysis of analogies among the production systems revealed that integrated production differed greatly from other production systems in most of the analyzed parameters. In bean pods cultivated according to the integrated production practices the highest levels of catechin, procyanidin dimers, *trans*-*p*-coumaroylaldaric acids, vanillic acid derivatives, and kaempferol glycosides in addition to low content levels of sugars were measured. Sugars are known to enhance flavonol content, and lower sugar contents could be correlated with higher flavonol content. Lester et al.,[35] for instance, reported that galactose caused a high relative activity of myricetin, kaempferol, and quercetin, while glucose and xylose caused a higher relative activity of quercetin. The conventional production system exhibited a moderate similarity to the other two distinctive clusters (Tables 2 and 3, Figure 1) in most of the analyzed chemical parameters such as ascorbic acid, catechin, and procyanidin dimers. Different content levels of individual phenols could be explained by increased environmental stress typical for organic types of production, which stimulates the synthesis of secondary metabolites.[10,12] On the other hand, there are many studies that do not confirm higher amounts of phenolics in the organic production systems.[11,14] Chinnici et al.[36] even reported that apples produced according to integrated practices have a higher total phenolic content and more flavanols compared to organically produced apples. A higher polyphenolic content in sustainable versus organically produced crops was also reported by Asami et al.,[37] who suggested that this could be attributed to the balance between the adequate nutrition of sustainable crops and pathogenic pressure, which led to the synthesis of polyphenolics.

Our results report the specific chemical composition of dwarf French bean pods from different production systems. For further analyses mineral content levels in soil and plants could be included in the study, and thus nutritional and water status of the crops can be evaluated in addition to biochemical profiles.

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Notes

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