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Research Article

# Potential of vegetable soybean cultivation in Lithuania

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## Abstract

The objective of the present study was to investigate the potential of vegetable soybean (Edamame) cultivation in Lithuania. Six soybean varieties were grown in an open field. Our data showed that the plants of the 'Chiba Green' variety were the shortest. Such plants had higher chlorophyll index and photosynthesis intensity. Variety 'Midori Giant' had more branches than plants of other varieties. The highest yield was produced by the plants of the 'Chiba Green' variety. Higher protein content was found in beans of the 'Chiba Green' variety. However, there were no differences found in soluble carbohydrates and micro- and macroelement contents between the varieties. In summary, the results revealed that of the tested varieties, the most suitable and useful for the cultivation under Lithuanian climate conditions was the 'Chiba Green' vegetable soybean variety.

***Keywords:*** cultivation opportunities; Edamame; protein; soluble carbohydrates; yield

## Introduction

In a changing climate, there are possibilities to grow plants in Lithuania and in the northern regions of other countries (northern Florida, North Dakota) that are normally grown in warmer regions and have high nutritional value. One of such plants could be vegetable soybeans. The legume family to which vegetable soybeans belongs consists of approximately 20000 species. This is the third-largest group of flowering plants, to which other important legumes, e. g. peas (*Phaseolus vulgaris*), mung bean (*Vigna radiata*) and pigeon pea (*Cajanus cajan*) belong (Lee *et al.*, 2015). Edamame or vegetable soybean (*Glycine max* L. Merrill), is a group of special cultivars of soybean. It is a self-pollinating, annual plant similar to beans. Vegetable soybean is a low input, short crop cycle and soil-enriching crop (Zhang *et al.*, 2017). The optimum time to harvest edamame is when the pods are still green or become yellow, immature (at R6 stage - full seed), and tight with fully developed immature green seeds, usually at 80-90% pod fill (Fehr and Caviness, 1977; Wang *et al.*, 2005; Zhang *et al.*, 2010). At this stage the flavor of edamame is nutty, sweet, buttery and beany (Wszelaki *et al.*, 2005).

Edamame has been highly valued in the human diet. It is rich in vitamins B and C, has calcium, iron, zinc, food fibre and protein. It is an excellent source of antioxidants and isoflavones (Medic *et al.*, 2014). In terms of protein content, soybeans are ahead of other protein crops and are only less inferior to meat and eggs.

Edamame is becoming increasingly popular worldwide (Medic *et al.*, 2014; Zeipina *et al.*, 2017). In recent decades, the demand for vegetable soybean has grown significantly due to its nutritional properties and

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the growing demand for healthy food (Zhang *et al.*, 2017). In countries such as Argentina, Australia, Israel, Mongolia, North American countries, New Zealand, and Thailand, edamame is widely grown for commercial purposes (Wang *et al.*, 2005). Vegetable soybean is one of the main crops in Korea, which is the third after rice and wheat (Lee *et al.*, 2015). The consumption of vegetable soybeans is rapidly increasing in Japan, Korea, China and Taiwan, and now gaining popularity as a fresh vegetable throughout the United States (Zhang and Kyei-Boahen, 2007). To meet growing demand, edamame is imported frozen from China and Taiwan into the U.S. (Nolen *et al.*, 2016).

Edamame cultivation opportunities have been explored in many regions – in central Pennsylvania (Sanchez *et al.*, 2005), in the Mississippi Delta (Zhang and Kyei-Boahen, 2007), in the mid-Atlantic United States (Carson *et al.*, 2011), in Central Alabama (Ogles *et al.*, 2016). It was also studied the possibilities of edamame genotypes for growing in the northern regions of some countries - in North Dakota (Duppong and Hatterman-Valenti, 2005), in northern Florida (Guo *et al.*, 2020). The results from these studies indicated that vegetable soybean could be successfully grown in these areas. In the first half of the 20th century, P. Dindonis researched soybean varieties in Latvia; however, they did not become popular in that country. In 2015, the research on soybean cultivation possibilities in Latvia was carried out in Pūre Horticultural Research Centre. Five Japanese soybean cultivars were grown and their productivity was determined (Zeipina *et al.*, 2016). According to research data higher yield was obtained for the 'Mizon Giant' plant.

Different soybean varieties are sensitive to changes in environmental conditions. It is necessary to investigate the interaction between a genotype and the environment to identify varieties that are stable in different environments (Calviño *et al.*, 2003). For edamame cultivation to be commercially viable, growers need to know which varieties are suitable for cultivation in a given area, i.e. it is important to select varieties suitable for the climate of each area and to know the peculiarities of their cultivation (Zhang *et al.*, 2017; Nagasuga, 2018; Djanta *et al.*, 2020). These vegetable soybeans are still a novelty in Lithuania no data on their cultivation have been found. Soy is a very light-sensitive plant. Day length and light intensity are important for flowering and the growing season length, affecting growth, height and, undoubtedly, yield. Varieties that need less light and heat are already being grown in Lithuania. The diversity of these plant varieties is considerable, differing in height and earliness. Therefore, it is not known which varieties are suitable for cultivation in Lithuania, what their vegetation period, nutritional value and productivity are.

We hypothesize that choosing vegetable soybean varieties suitable for the Lithuanian climate would provide an opportunity to expand the assortment of protein-rich food plants.

The work objective was to select vegetable soybean varieties suitable for growing under Lithuanian conditions and to determine the nutritional value indicators in soybeans.

## Materials and Methods

### *Growing conditions*

The experiments were carried out at the Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry in 2015-2016. Six varieties of vegetable soybeans were investigated: 'Aoshizuku' (Japan), 'Chiba Green' (USA), 'Kaohsiung No9' (Japan), 'Midori Giant'(USA), 'Sapporomidori' (Japan) and 'Sayamusume' (Japan).

The experiment was conducted on Idg8-k Calc(ar)i - Epihypogleyic Luvisolls (LVg-p-w-cc) (WRB, 2014), texture - sandy with sandy clay loam in deeper layers. The soil, on which the soya was grown, was low in nitrogen (37.3 - 38.5 kg $ha^{-1}$), average humus content (2.76%), rich in available phosphorus as $P_2O_5$ (181 - 214 mg $kg^{-1}$), averagely rich in potassium as $K_2O$ (121 - 122 mg $kg^{-1}$), and rich in calcium and magnesium. Soil $pH_{KCl}$ - 7.5. The soybean was sown in rows at 70 cm spacing. Plot area: 3.50 x 2.80 = 9.8 $m^2$, record plot area - 4.9 $m^2$. The experiment was conducted with three replications, arranged randomly. During the growing season mechanical chisel loosening was used between rows. The soya was seeded at the end of May and harvested at the end of September 2015 and at the beginning of October 2016.

**Figure 1.** Vegetable soybean plants in the research field during the experiments

*Biometric measurements*

Phenological and biometric observations were carried out. During vegetation the plant height at flowering (plant height was measured up to an inflorescence) was measured and the number of branches per plant was calculated. These measurements were performed in ten replicates ($n$ = 10). The edamame yield per plant was recorded at the end of the harvest. The weight of 100 pods (2-3 beans per pod) and 25 seeds were determined.

*Determination of photosynthetic indices*

Non-destructive measurements of leaf chlorophyll content were performed using a chlorophyll and flavonoid meter (Dualex® 4, Scientific, USA). The first fully matured leaves of 10 plants per treatment were measured.

*Determination of photosynthetic intensity*

The photosynthetic rate was determined at 9:00-12:00 am by using an LI-6400XT portable open flow gas exchange system (Li-COR Biosciences, Lincoln, USA). Reference air [$CO_2$] (400 μmol $mol^{-1}$), light intensity (1000 μmol $m^{-2}$ $s^{-1}$) and the flow rate of gas pump (500 mmol $s^{-1}$) were set.

*Determination of soluble carbohydrates*

Concentrations of water-soluble carbohydrates (WSC) in water extracts of dried samples were measured spectrophotometrically using the anthrone reagent. We prepared stock standards and working standards. Stock standard: 100 mg glucose was weighed and carefully added to 100 ml distilled water (100 mg glucose per 100 ml distilled water). Working standard: 10 ml of stock standard solution was diluted in 100 ml distilled water in a volumetric flask. We took 0.2 to 1 ml of working standard solution from five different tubes and added water to make up 1 ml per tube, then added 4 ml of anthron reagent (200 mg of anthron reagent was dissolved in 100 ml of concentrated $H_2SO_4$) and mixed the contents. We covered the tube for 10 minutes, then the tube was cooled to room temperature and we measured the optical density using a red filter by a photoelectric colorimeter at 620 nm. At the same time, a blank solution was prepared to contain 1 ml of distilled water and 4 ml of anthrone reagent. The calibration curve was plotted. From the calibration curve, we calculated the sugar concentration in the sample.

*Determination of protein*

Protein content was determined by the Kjeldahl method. Approximately 1 g of raw material was hydrolyzed with 15 mL concentrated sulfuric acid ($H_2SO_4$) containing two copper catalyst tablets in a heat block (Kjeltec system 2020 digestor, Tecator Inc., Herndon, VA, USA) at 420 °C for 2 h. After cooling, $H_2O$ was added to the hydrolysates before neutralization and titration. The amount of total nitrogen in the raw materials was multiplied with both the traditional conversion factor of 6.25 and species-specific conversion factors to determine total protein content.

*Determination of macro- and microelements*

The contents of macro- and microelements in vegetable soybeans were determined using the microwave digestion technique combined with inductively coupled plasma optical emission spectrometry. Complete digestion of dry vegetable soybean matter (0.5 g) was achieved with 65% $HNO_3$ and 30% $H_2O_2$ (5:3) using the microwave digestion system Multiwave GO (Anton Paar GmbH, Austria). The digestion program was as follows: 1) 150 °C reached within 3 min, digested for 10 min; and 2) 180°C reached within 10 min, digested for 10 min. The mineralised samples were diluted to 50 mL with deionized water. The elemental profile was analysed by ICP - OES spectrometer (Spectro Genesis, SPECTRO Analytical Instruments, Germany). The operating conditions employed for ICP-OES determination were 1300W RF power, 12 L $min^{-1}$ plasma flow, 1.0 L $min^{-1}$ auxiliary flow, 0.8 L $min^{-1}$ nebulizer flow, and 1.0 mL $min^{-1}$ sample uptake rate. The analytical wavelengths (nm) chosen were: B I 249.773 nm, Ca II 445.478 nm, Cu I 324.754 nm, Fe II 259.941 nm, K I 766.491 nm, Mg II 279.079 nm, Mn II 259.373 nm, Na I 589.592 nm, P I 213.618 nm, S I 182.034 nm, and Zn I 213.856 nm. The calibration standards were prepared by diluting a stock multi-elemental standard solution (1000 mg $L^{-1}$) in 6.5% (v/v) nitric acid, and by diluting stock phosphorus and sulphur standard solutions (1000 mg $L^{-1}$) in deionized water. The calibration curves for all the studied elements were in the range of 0.01–400 mg $L^{-1}$.

*Statistical analysis*

Data were tested using one-way analysis of variance and the means were compared by Tukey's least significant differences (LSD). Statistical significance was evaluated at $p \leq 0.05$. The correlation coefficient was determined by the statistical method of path coefficient analysis using STAT-ENG programme.

## Results

The average air temperature of May-July 2015 was close to the multiannual average (Table 1). August was particularly warm; the air temperature was 3 °C higher than the multiannual average. In September, the air temperature was also above the multiannual average. During the vegetation period of 2016, the air temperature was above the multiannual average. In May-July 2016 the air temperature was 0.9-3.6 °C higher compared to the same months of 2015. In June and August 2015, when humidity was necessary for plant growth, it was very dry. July 2016 was particularly rainy; precipitation was 15.9 mm above the multiannual average. The precipitation in May and September was significantly lower than the multiannual average.

During both years, the soybean germinated 6 days after sowing (Table 2). The best germination showed by the 'Aoshizuku' variety. The plants of all soybean varieties developed similarly, except the 'Aoshizuku' variety. At the time of flowering of other varieties (R2 stage - full flowering), 'Aoshizuku' plants began to form buds (R1 stage - beginning flowering). The plants of the 'Aoshizuku' variety began to form pods, while the plants of other varieties began to form seeds. Thus, the development of this cultivar was behind other cultivars at one stage of growth. The plants of the 'Aoshizuku' variety did not produce seeds and were not harvested. In both years the duration of the vegetation period varied little. In 2015 the duration of the soybean vegetation period was 117 days, while in 2016 it was slightly longer - 126 days.

**Table 1.** Air temperature and precipitation amount

| Month | Air temperature (°C) | | | Precipitation (mm) | | |
|---|---|---|---|---|---|---|
| | 2015 | 2016 | Multiannual | 2015 | 2016 | Multiannual |
| **May** | 12.0 | 15.6 | 12.3 | 63.2 | 11.2 | 50.7 |
| **June** | 15.9 | 17.4 | 15.9 | 26.8 | 45.8 | 71.2 |
| **July** | 17.6 | 18.5 | 17.3 | 91.2 | 107.6 | 75.3 |
| **August** | 19.7 | 17.4 | 16.7 | 4.6 | 77.4 | 78.4 |
| **September** | 14.0 | 13.6 | 12.1 | 43.4 | 13.4 | 58.7 |

Data of Babtai agrometeorological station, using iMETOS program. Babtai

**Table 2.** Duration of growth stages of different vegetable soybean varieties (the number of days)

| Growth stages | 'Aoschizuku' | 'Chiba green' | 'Kaohsiung No9' | 'Midori Giant' | 'Sapporo-midori' | 'Saymusume' |
|---|---|---|---|---|---|---|
| Seeding-VE | 7 | 7 | 7 | 7 | 7 | 7 |
| VE | 6 | 7 | 7 | 7 | 7 | 7 |
| Germination | 6 | 7 | 7 | 7 | 7 | 7 |
| VC-V1 | 11 | 11 | 11 | 11 | 11 | 11 |
| V1-V2 | 10 | 10 | 10 | 10 | 10 | 10 |
| V3 | 8 | 7 | 7 | 7 | 7 | 7 |
| V3-R1 | 25 | 7 | 7 | 7 | 7 | 7 |
| R1 | 9 | 18 | 18 | 18 | 18 | 18 |
| R2 | 14 | 7 | 7 | 7 | 7 | 7 |
| R3 | 6 | 9 | 9 | 9 | 9 | 9 |
| R4-R7 | 20 | 15 | 15 | 15 | 15 | 15 |
| R8 | - | 20 | 20 | 20 | 20 | 20 |

Growth stages: VE – emergence, VC – cotyledon, V1 – first node, V2 – second node, V3 – third node, R1 – beginning flowering, R2 – full flowering, R3 – begining pod, R4 – full pod, R5 -begining seed, R6 – full seed, R7 – beginning maturity, R8 – full maturity

The results of biometric measurements of different vegetable soybean varieties are shown in Table 3. In 2015, the soybean plants of all varieties were shorter than in 2016. During both years of the study, the highest plants of the studied soybean cultivars were those of 'Kaohsiung No9'. They were 9.9-40.8% higher compared to other cultivars, respectively. 'Chiba Green' soybean plants were the shortest during both years of the study. The plants of this variety were compact, the branches arranged in one plane. The plants of 'Midori Giant' and 'Kaohsiung No9' cultivars formed more branches during both years of the study compared to other cultivars. The 'Aoshizuku' plants formed the least number of branches.

**Table 3.** Vegetable soybean plant height and number of branches

| Varieties | Plant height (cm) | | | Number of branches (units) | | |
|---|---|---|---|---|---|---|
| | 2015 | 2016 | Average | 2015 | 2016 | Average |
| 'Aoshizuku' | 44.67 | $46.23^{B}$ | 45.45 | $3.33^{B}$ | $3.00^{B}$ | $3.17^{B}$ |
| 'Chiba Green' | $34.93^{B}$ | $44.03^{B}$ | $39.48^{B}$ | 4.00 | 4.00 | 4.00 |
| 'Kaohsiung No9' | $50.03^{A}$ | $61.17^{A}$ | $55.60^{A}$ | 4.33 | 4.00 | $4.17^{A}$ |
| 'Midori Giant' | 42.70 | $58.50^{A}$ | 50.60 | $4.67^{A}$ | $4.33^{A}$ | $4.50^{A}$ |
| 'Sapporomidori' | 38.20 | 48.90 | 43.55 | 3.67 | 3.30 | $3.49^{B}$ |
| 'Sayamusume' | 42.20 | 54.43 | 48.32 | 4.00 | 3.67 | 3.84 |
| $LSD_{05}$ | 4.94 | 3.75 | 5.56 | 0.61 | 0.51 | 0.16 |

A – significantly ($p>0.05$) more than the average; B – significantly less than the average

Note: measured to the last inflorescence on the main stem

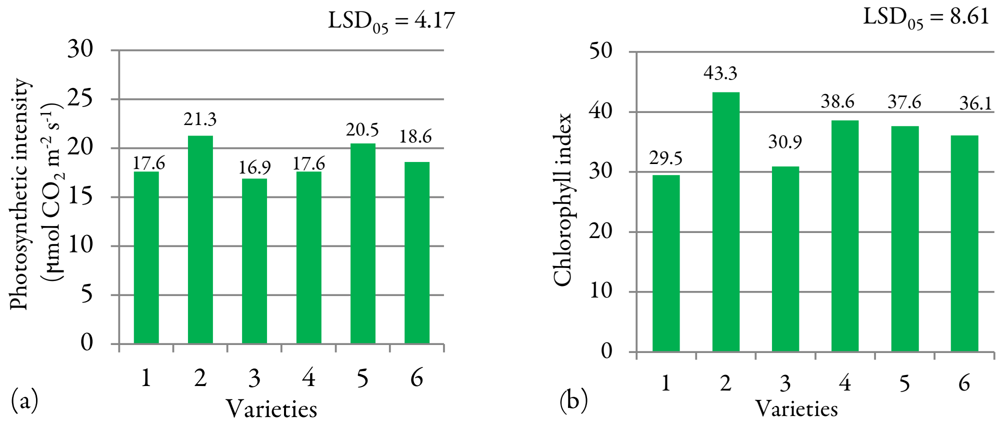


**Figure 2.** Photosynthetic intensity (a) and chlorophyll index (b) in the leaves of different varieties of vegetable soybean

(1 – Aoshizuku, 2 - Chiba Green, 3 - Kaohsiung No9, 4 - Midori Giant, 5 – Sapporomidori, 6 – Sayamusume) (average of 2015-2016)

The photosynthetic intensity in soybean plants varied between varieties (Figure 1a). 'Chiba Green' cultivars showed the highest photosynthetic intensity (significantly more than in the leaves of the Kaohsiung variety). The photosynthetic intensity of 'Sapporomidori' cultivars was slightly lower than that of 'Chiba Green' plants. The photosynthetic intensity in 'Aoshizuku', 'Midori Giant' plants was the same. The plants of the 'Kaohsiung No9' soybean variety had the lowest photosynthetic intensity. Chlorophyll index in soybean leaves varied depending on the variety (Figure 1b). The leaves of the 'Chiba Green' variety showed the highest chlorophyll indexes (significantly more than in the 'Aoshizuku' and 'Kaohsiung No9' leaves). In the leaves of 'Midori Giant', 'Sapporomidori', and 'Sayamusume' the chlorophyll indexes were similar.

The contents of elements in soybeans depended on the variety (Table 4). The highest potassium content was found in 'Midori Giant' soybean seeds (significant difference) and the highest calcium was determined in 'Sapporomidori' seeds (significant difference). Magnesium content was the highest in the seeds of the 'Sayamusume' variety. There was little difference in iron and zinc contents in the soybean cultivars studied. 'Chiba Green' plants accumulated the lowest levels of potassium, calcium, magnesium and phosphorus in their seeds.

**Table 4.** Element contents in the seeds of different varieties of vegetable soybean (average of 2015-2016)

| Varieties | Elements (mg $g^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Potasium (K) | Calcium (Ca) | Magnesium (Mg) | Phosphorus (P) | Iron (Fe) | Zinc (Zn) |
| 'Chiba Green' | 34.14 | $1.27^B$ | $17.76^B$ | 6.98 | 0.41 | 0.31 |
| 'Kaohsiung No9' | 34.96 | 1.47 | $18.41^B$ | 7.68 | 0.39 | 0.32 |
| 'Midori Giant' | $36.31^A$ | 1.59 | 18.82 | 7.41 | 0.38 | 0.32 |
| 'Sapporomidori' | 34.71 | $2.01^A$ | $21.96^A$ | 7.14 | 0.40 | 0.30 |
| 'Sayamusume' | 35.48 | 1.90 | $22.20^A$ | 7.32 | 0.39 | 0.30 |
| $LSD_{05}$ | 1.06 | 0.19 | 1.32 | 0.42 | 0.06 | 0.02 |

A – significantly ($p>0.05$) more than the average; B – significantly less than the average

Soybean yield depended on the year and the variety (Table 5). The plants of 'Chiba Green' and 'Kaohsiung No9' cultivars were more productive in 2015, and in 2016 the yield of these plants was lower. The plants of 'Midori Giant', 'Sapporomidori', and 'Sayamusume' were more productive in 2016 compared to the yield of the same varieties obtained in 2015. The soybean variety 'Chiba Green' had the highest yield per plant (significant difference) during both years of the study (Table 5). The yield per plant from ‘Kaohsiung No9’, ‘Sapporomidori’ and ‘Sayamusume’ varieties was almost the same. In terms of pod yield per plant, the soya varieties lined up as follows: ‘Chiba Green’> ‘Midori Giant’> ‘Sapporomidori’> ‘Sayamusume’> ‘Kaohsiung No9’.

**Table 5.** Pod yield of different varieties of vegetable soybean

| Varieties | Yield (kg plant$^{-1}$) | | |
|---|---|---|---|
| | 2015 | 2016 | Average |
| ‘Chiba Green’ | 0.173$^{A}$ | 0.166$^{A}$ | 0.170$^{A}$ |
| ‘Kaohsiung No9’ | 0.085 | 0.054$^{B}$ | 0.070 |
| ‘Midori Giant’ | 0.083 | 0.125 | 0.104 |
| ‘Sapporomidori’ | 0.063$^{B}$ | 0.089 | 0.076 |
| ‘Sayamusume’ | 0.068$^{B}$ | 0.074 | 0.071 |
| $LSD_{05}$ | 0.012 | 0.039 | 0.035 |

A – significantly (p>0.05) more than the average; B – significantly less than the average

‘Chiba Green’ soybean plants formed the largest number of Category I (2–3 seeds per pod) (significant difference) and II (1 seed per pod) pods (Table 6). Depending on the variety, the yield of Category I pods was 55.7–75.3% of the total yield. The lowest number of Category I pods was obtained from ‘Kaohsiung No9’ cultivars. The plants of this variety formed the highest yield of Category III (non-commercial) pods. The yield of Category I pods from ‘Sapporomidori’ and ‘Sayamusume’ plants was the same.

**Table 6.** Harvest quality data of different varieties of vegetable soybeans (average of 2015-2016)

| Varieties | Yield (kg plant$^{-1}$) | | |
|---|---|---|---|
| | Category I | Category II | Category III |
| ‘Chiba Green’ | 0.128$^{A}$ | 0.037 | 0.005 |
| ‘Kaohsiung No9’ | 0.039$^{B}$ | 0.022 | 0.010$^{A}$ |
| ‘Midori Giant’ | 0.065 | 0.032 | 0.007 |
| ‘Sapporomidori’ | 0.049 | 0.019 | 0.005 |
| ‘Sayamusume’ | 0.047 | 0.017 | 0.007 |
| $LSD_{05}$ | 0.020 | 0.016 | 0.002 |

A – significantly (p>0.05) more than the average; B – significantly less than the average

The weight of 100 pods of the ‘Chiba Green’ cultivar was the highest (Figure 2a). It was 25.2–41.6% (significant difference) higher than the weight of 100 pods of ‘Midori Giant’ and ‘Sapporomidori’ cultivars, respectively. ‘Sapporomidori’ cultivar had the lowest 100 pod weight. ‘Kaohsiung No9’ and ‘Sayamusume’ varieties demonstrated almost the same weight of 100 pods. The average weight of 25 seeds of edamame varieties for two years is shown in Figure 2b. The weight of 25 edamame seeds was almost the same for both years. In 2015, depending on the variety, it ranged from 31 to 52 g, and in 2016 - from 35 to 53 g. The 25-seed weights of ‘Chiba Green’ and ‘Sayamusume’ soybean varieties were the highest and significantly higher compared to the 25-seed weights of ‘Kaohsiung No9’ and ‘Midori Giant’ varieties. The 25-seed weights for soybean varieties ‘Kaohsiung No9’ and ‘Midori Giant’ were the lowest.

Protein and soluble carbohydrate contents in edamame seeds are presented in Figure 3. The protein content in soybeans depended more on the variety than on the year (Figure 3a). The year of growth had the greatest effect on the protein content of ‘Chiba Green’ beans. In 2015, the beans of this variety accumulated 6.3% more protein compared to 2016. In both years of the study, ‘Chiba Green’ soybeans accumulated the significantly highest levels of protein. The protein content of ‘Midori Giant’ and ‘Sapporomidori’ beans did not differ much and was 1.2 - 3.4% higher, respectively, compared to that of ‘Kaohsiung No9’ and ‘Sayamusume’ beans. The latter accumulated the lowest protein content in seeds.

The soluble carbohydrate contents in soybeans depended on the year of cultivation and the variety (Figure 3b). In 2015, all cultivated soybean varieties accumulated 5.0 - 13.5% more soluble carbohydrates compared to 2016. However, during both years of the study, the highest levels of soluble carbohydrates were accumulated in 'Kaohsiung No9' variety soybeans (significant difference). The soluble carbohydrates contents in other varieties of beans were almost uniform and ranged from 16.1 to 16.6%.

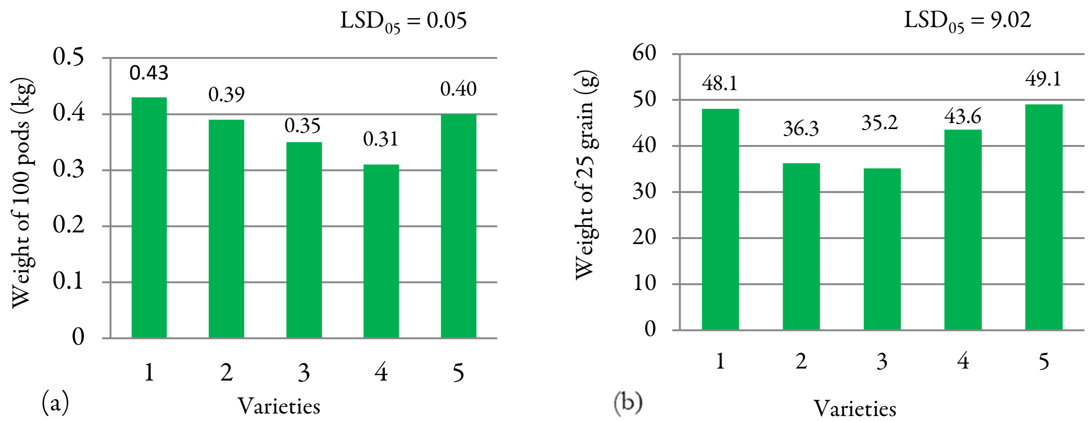


**Figure 3.** Weight of 100 pods (a) and 25 seeds (b) of different varieties of vegetable soybean
(1 – Aoshizuku, 2 - Chiba Green, 3 - Kaohsiung No9, 4 - Midori Giant, 5 – Sapporomidori) (average of 2015-2016)

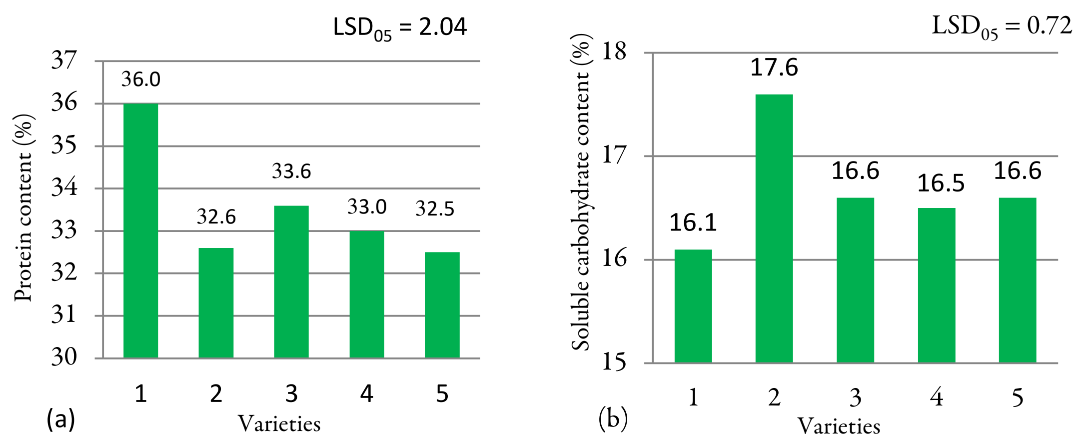


**Figure 4.** Protein (a) and soluble carbohydrate (b) contents in seeds of different varieties of vegetable soybean
(1 – Aoshizuku, 2 - Chiba Green, 3 - Kaohsiung No9, 4 - Midori Giant, 5 – Sapporomidori) (average of 2015-2016)

## Discussion

Soybean growth, development, and yield are significantly influenced by a variety and a sowing date (Muhammad *et al.*, 2009; Shegro *et al.*, 2010; Santos *et al.*, 2013; Li *et al.*, 2014; Matsuo *et al.*, 2016; Bakal *et al.*, 2017). In our studies, six edamame varieties were grown; however, one of them - 'Aoshizuku' did not form pods, therefore, the crop was not harvested. The other five varieties grew and developed similarly. Plant height indicates the phenology and growth of the crop (Shah *et al.*, 2017). The average plant height can range from 20 to 150 cm, depending on the environment, and is typical of the variety in question. In our studies, the height of different soybean varieties was different. Our data showed that the plants of the 'Chiba Green' variety were the shortest and the plants of the 'Kaohsiung No9' variety were the highest (Table 3). The data by Ngalamu *et al.* (2013) suggests that a high seed yield potential is associated with the number of branches per plant, the number of productive pods per plant and leaf area. Contrary to Ngalamu *et al.* data, under our conditions, 'Kaohsiung No9' and 'Midori Giant' soybean varieties formed more branches, but their yield was lower than that of soybean which had fewer branches.

The process of plant photosynthesis is usually associated with higher yields; however, the relationship between them is not clear. It is believed that photosynthetic intensity depends on the earliness of a variety. Early cultivars had higher peak rates of photosynthesis compared to those of later-maturing cultivars. However, the rate of photosynthesis in early-maturing cultivars decreased rapidly after reaching the peak, while the leaves of later cultivars retained their photosynthetic activity for much longer (Nagasuga, 2018). According to our data, the photosynthetic intensity of the investigated soybean plants was different (Figure1a). 'Chiba Green' cultivars had the highest photosynthetic intensity, and the chlorophyll index was the highest in the leaves of these plants (Figure 1a, b). Besides, these plants were the most productive. Therefore, it can be argued that photosynthetic intensity influences the yields.

The chemical composition of soybeans depends on genetic and environmental factors. The main mineral elements in soybeans are calcium, phosphorus, potassium, and they also contain zinc, copper, iron, and manganese (Gupta *et al.*, 1976). Biel *et al.* (2018) stated that the content of mineral elements in soybeans depends on the variety. Our research data were similar to those of Biel *et al.* (2018)proving that the contents of elements in soybean seeds were dependent on the variety. The highest potassium content was found in 'Midori Giant' beans, highest calcium - in 'Sapporomidori' beans, and highest magnesium - in 'Sayamusume' beans (Table 4).

Many researchers indicate that soybean yield depends on environmental conditions (temperature, precipitation) (Mebrahtu and Mohamed, 2006; Hu and Wiatrak, 2012; Zeipina *et al.*, 2017). Hu and Wiatrak (2012) reported that unfavourable environmental conditions harmed the growth, development, and yield of soya. Photoperiod, temperature, and precipitation with delayed planting affect the duration of developmental stages, the number of branches and pods, plant height, leaf area index (LAI), and hence the grain yield. Higher air temperatures in May–June and significantly rainier months of June and July in 2016 contributed to the fact that soybean plants were taller in our experiments compared to those in 2015. The soybean yield is also influenced by agrotechnical factors (e.g., irrigation) (Duppong and Hatterman-Valenti, 2005; Zeipina *et al.*, 2017). Also, the yield depends on the genotype and variety (Duppong and Hatterman-Valenti, 2005; Ngalamu *et al.*, 2013; Zeipina *et al.*, 2017). According to other researchers, both soybean varieties and planting dates influence soybean growth, development, and yield (Shegro *et al.*, 2010, Rehman *et al.*, 2014). Other scientists stated that the 'Midori Giant' cultivar was characterised by higher average seed weight and high yield compared to other cultivars studied (Zhang and Kyei-Boahen, 2007; Carson *et al.*, 2011; Ogles *et al.*, 2016). Contrary to the data collected by those researchers, the 'Midori Giant' soybean variety demonstrated a good yield in our studies (Table 5). However, the most productive were 'Chiba Green' soybean plants.

According to Sirisomboon *et al.* (2007), green soybeans can be classified into two main categories according to their use: pods with 3 or 2 seeds each, and pods with only 1 seed; the remaining pods are non-commercial (seedless, deformed). In our research, all cultivated soybean varieties formed more pods with 2-3 beans inside. This accounted for 55.7 - 75.3% of the total yield per plant, depending on the variety. The highest yield of non-commercial pods was formed by 'Kaohsiung No9' plants (Table 6).

Consumers of edamame prefer bright green pods, two or more beans per pod, and large seed size (Montri *et al.*, 2006). Seed size is one of the soybean quality indicators (Konovsky *et al.*, 1994). Mebrahtu and Mohamed (2006) reported that soybean yields depended on environmental conditions, however, plant height and 100-seed weight were more or less stable. According to Ogles and other researchers (2016) who conducted studies of soybean cultivars of different earliness in Central Alabama, the 25-seed weight of soybeans varied depending on the cultivar. The data collected by Ogles *et al.* and our research suggests that the 25-seed weight depended on the variety. 'Chiba Green' and 'Sayamusume' soybean cultivars had the highest 25-seed weight (Figure 2b).

Genetic and environmental factors have a major influence on the internal quality of soybean seeds (Krishnan, 2000; Medic *et al.*, 2014; Zeipina *et al.*, 2017). Sanchez *et al.* (2005) indicated that bean quality was dependent on cultivar. Li *et al.* (2014) found that delayed soya planting harmed both seeds yield and quality. Rao *et al.* (2002) reported that soybeans were low in fat (13–16%) but high in protein (33–39%). Yin and Vyn (2005) found that soybeans averaged about 41% protein. The protein content of soybeans was depended on the year of cultivation (Carson *et al.*, 2011), planting time (Muhammad *et al.*, 2009; Rehman *et al.*, 2014). However, no significant difference was recorded between protein percentages in different cultivars (Rehman *et al.*, 2014; Shah *et al.*, 2017). In contrast to the data from Shah, Regman, and other authors, and in accordance with Muhammad our studies showed that the soya variety affected on protein content in beans. 'Chiba Green' beans had the highest protein content (Figure 3a).

Soybean seeds are also an important source of carbohydrates (Medic *et al.*, 2014). They contain about 33% carbohydrates (Hou *et al.*, 2009). Xu *et al.* (2016) results showed that the 'Asmara' soybean cultivar at the R6 stage had accumulated more carbohydrates compared to the 'Mooncake' cultivar. According to Xu *et al.* and our data, the carbohydrate content in beans depended on the variety. Significantly higher carbohydrate content was found in 'Kaohsiung No9' soybeans (Figure 3b).

To improve soybean yield, it is important to establish the relationship between yield and quantitative physiological indicators (Sarutayophat, 2012; Nagasuga, 2018). Arshad *et al.* (2006) reported that the relationship between soybean yield and its components had been investigated, and the results obtained were used by many researchers as a tool in the selection of soybean varieties. The relationship between seed quality (oil, protein, sugar contents), plant height and yield in soybean has also been examined (Yin and Vyn, 2005; Li *et al.*, 2013, Matsou *et al.*, 2016). It has been established that there is no significant difference between protein concentration and seed yield (Yin and Vyn, 2005). Matsou *et al.* (2016) found that soybean yield was negatively correlated with the pod rate, 100-seed weight, and protein content. The research results of Li *et al.* (2013) showed that soybean yield was positively correlated with 3-seed plants (r = 0.81), 2-seed plants (r = 0.76) and 100-seed weight (r = 0.47), and negatively correlated with plant height (r = - 0.75). In contrast to Yin and Vyn, our data showed a strong correlation (r = 0.99) between yield and protein content in soybeans. However, a moderate correlation (r = 0.54) was found between yield and 100 pod weight, and a weak correlation (r = 0.41) was found between yield and 25-grain weight. Thus when choosing soybeans and to obtain a higher yield, it is necessary to pay attention to the number of seeds per pod, 100-seed weight, plant height and seed length (Sarutayophat, 2012).

In the summary, vegetable soybean varieties suitable for cultivation under Lithuanian climatic conditions will provide an opportunity to expand the range of protein-rich foods plants not only in Lithuania, but also in countries with similar climates.

## Conclusions

In order to obtain a good green soybean yield, it is necessary to choose varieties that are suitable for growing in that climate condition. All studied soybean varieties are suitable for cultivation under Lithuanian climatic conditions, except for the variety 'Aoshizuku', which did not reach technical maturity and their yield was not assessed. The seeds of all tested soybean varieties were characterized by good internal seed quality. Protein content in the seeds ranged from 32.5 to 36 %, carbohydrates - from 16.1 to 17.6 %. It can be stated that 'Chiba Green' is the most suitable vegetable soybean variety for cultivation under Lithuanian climatic conditions. The plants of this variety showed higher photosynthetic intensity, and higher chlorophyll and nitrogen balance index (NBI) in leaves. They demonstrated the highest yield per plant, the weight of 100 pods, and protein content in the seeds.

## Authors' Contributions

JJ designed the work and JJ, AA and VVK wrote the manuscript. All authors read and approved the final manuscript.

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## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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