



Genotypic difference in postharvest characteristics of hardy kiwifruit (*Actinidia arguta* and its hybrids), as a new commercial crop

Part I. Sensory profiling and physicochemical differences

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ABSTRACT

Hardy kiwifruit, *Actinidia arguta* (Siebold et. Zucc.) Planch ex Miq. and *A. purpurea* Rehd. are species with healthy fruit and high frost resistance. Despite being still exotic they start to be grown commercially, therefore they may become an important supplement to the current fruit production in regions with colder climate such as north European countries. The main goal of the study was to assess the genotypic variability of physicochemical and sensory characteristics of *A. arguta* fruit at the eating ripeness stage. Seven *A. arguta* genotypes and two hybrids (*A. arguta* × *A. purpurea*) including four selected at Warsaw University of Life Sciences, Poland, were evaluated via physicochemical measurements and via quantitative descriptive analysis by a trained sensory panel. The study consisted of two-year evaluation. The study showed high diversity of postharvest physicochemical characteristics of the examined hardy kiwifruit: firmness, soluble solid content, titratable acidity as well as mass and shape. This fruit diversity is significantly increased by the *A. arguta* and *A. purpurea* hybrids which are responsible for large part of the colour differences among the genotypes, revealing high potential of cross-breeding of these species. On the other hand, the overall sensory characteristics of the examined genotypes are similar. In general, ripe hardy kiwifruit are characterised with soft, sour and averagely astringent skin with additional irritating note. The taste of the soft, jelly-like pulp is dominated by fruity and sweet tastes with low admixture of irritating, vinous, astringent and sour tastes.

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1. Introduction

New fruit are being constantly introduced on the local and international markets (Le Bellec, Vaillant, & Imbert, 2006; Nerd & Mizrahi, 2000; Prohens, Rodríguez-Burruezo, & Nuez, 2003). The main driver of their introduction is an increasing demand for new tastes and innovative as well as healthy foods. In the case of fruit of known species an additional driver may be to broaden the geographic range of their cultivation and widen the range of their physicochemical and sensory variability which may influence consumer acceptance.

Kiwifruit is the main representative of the *Actinidia* genus. It is known around the world and highly appreciated because of its pro-healthy properties (Collins, Horsa, Hotten, Riddoch, & Collins, 2001; Ferguson & Ferguson, 2003; Jung et al., 2005). The other edible and very promising *Actinidia* species is *A. arguta* (Siebold et Zucc.) Planch. ex Miq. called also hardy kiwifruit, Bower Actinidia, Baby kiwi or Mini kiwi. One of its advantages is good winter hardiness (up to −30 °C in

midwinter) and shorter vegetation period (about 150 days) in comparison to kiwifruit (about 220–240 days). Therefore, hardy kiwifruit may not only become a further extension of the kiwifruit offer of the traditional kiwifruit producers such as New Zealand, but may also become the first *Actinidia* commercially cultivated in regions with colder climate such as north European countries. Despite being still and exotic fruit, *A. arguta* is starting to be grown commercially in New Zealand,¹ USA,² Canada, Japan and Chile as well as in several European countries such as France,³ Switzerland, Germany and Belgium⁴ (Ferguson, 1999; Okamoto & Goto, 2005; Williams, Boyd, Mc Neilage, Macrae, & Ferguson, 2003).

Hardy kiwifruit contains high level of vitamin C (up to 185 mg/100 g fresh weight), high level of phenolics as well as P, Ca, Fe and Zn minerals and can be considered to be the richest dietary source of lutein among commercially available fruits (Fisk, Mc Daniel, Strik, & Zhao, 2006; Latocha, 2007; Latocha & Krupa, 2008; Latocha, Krupa,

¹ www.nzkiwiberry.com.

² www.kiwiberry.com.

³ www.oscar.eu/pages/oscar_kiwai.aspx.

⁴ www.freshplaza.com/news_detail.asp?id=29709.

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Wołosiak, Worobiej, & Wilczak, 2010; Nishiyama, Fukuda, & Oota, 2005; Nishiyama et al., 2004; Okamoto & Goto, 2005). The above facts justify why *A. arguta* fruit, like kiwifruit, is sometimes called a “healthy fruit”.

A. purpurea Rehd., called also Purple kiwi, is a very closely related species to *A. arguta*. It is similarly frost hard but its fruit ripening occurs little earlier than in the *A. arguta* case.

A. arguta fruit are small, grape-sized, with thin, edible, predominantly green skin. The fruit is very aromatic with a sweet, intense flavour that has been compared to ripe strawberry, blackcurrant, pineapple, pear, banana, melon and other tropical flavours (Matich et al., 2003) and can be used for fresh eating and/or for jam and wine production. *A. purpurea* fruit are about the same size with *A. arguta* but have red skin and flesh.

The studies of hardy kiwifruit presented so far, focused on the most popular and most frequently cultivated cultivar ‘Ananasnaya’ (Fisk, Silver, Strik, & Zhao, 2008; Fisk et al., 2006; Strik & Hummer, 2006). The consumer preferences towards *A. arguta* fruit have not been examined either. The experience based on evaluation of other fruits shows that consumer decision to buy a particular fruit may be influenced by its external features such as colour, shape and size (Bruhn, 1995; Crisosto, Crisosto, & Metheney, 2003; Gamble, Jaeger, & Harker, 2006) as well as its sensory characteristics (Kader, 2008; Tomala, Baryłko-Pikielna, Jankowski, Jeziorek, & Wasiak-Zys, 2009). The year-to-year repeatability of these features has impact on consumer “memorability” which decides whether they want to buy a fruit again in next season.

The main goal of the study was to assess the genotypic variability of postharvest physicochemical and sensory characteristics of *A. arguta* fruit at the eating ripeness stage. The evaluated features belong to three groups: physical (firmness, mass, shape and colour), chemical (soluble solid content and titratable acidity) and sensory (texture and flavour attributes). We study the range of the evaluated characteristics and compare their variability between different genotypes and within individual ones. Moreover, basing on two-year results we indicate seasonal variability of the evaluated features. Results of the study provide a “pattern” of the physicochemical and sensory characteristics of the examined *Actinidia* fruit.

2. Materials and methods

2.1. Experimental field location, soil and climate conditions

The experiment was held in the years 2005 and 2006. Plants were cultivated at the experimental field of the Department of Environmental Protection, Warsaw University of Life Sciences, (WULS), Poland (N 52°13'; E 21°00') on sandy loam soil. Plants were pruned regularly according to Strik (2005) and irrigated during the drought periods.

The temperature and precipitation were routinely recorded during both years of the experiment. The vegetation season of the year 2005 was relatively dry with low precipitation since August till October. In 2006 a drop of precipitation in June as well as in September and October but an extremely high level of precipitation in August (about three times exceeding the long-term August average) were observed. The recorded temperatures differ mainly in July and September – higher temperatures than the long-term average were recorded in July and September of 2005 and especially in 2006.

2.2. Fruit sample preparation

The investigation included five popular cultivars of *A. arguta*: ‘Ananasnaya’, ‘Weiki’, ‘Jumbo’, ‘Geneva’ and ‘74-49’; and four promising genotypes selected in the breeding programme held at the WULS (Latocha & Krupa, 2007). Two of these genotypes are the first examined hybrids of *A. arguta* and *A. purpurea*. For the cv.

Ananasnaya abbreviation ‘Anna’ will be used in presented figures. The full list of the tested genotypes and the plant origins are given in Table 1 and their high resolution photograph can be found in the supplementary material, see Fig. A1.

Fruits were picked from shrubs that were 9 years old at the beginning of the study, in the year 2005. Fruit were picked at their eating ripeness stage, randomly, from the different part of plants. The choice of the harvest date was based on the tactile observation of fruit softness. As the beginning of ripening of various *A. arguta* genotypes differed, the harvest date was chosen at the moment when at least 15–20% of soft fruit were observed at plants of each cultivar. Only soft fruits were collected. The harvest lasted for a few days. Physicochemical analyses were made right after collecting the fruit. For sensory assessment the time period between the harvest of particular fruit and panel evaluation was 2–4 days. Within that time fruits were stored in cold air store at +1 °C but twelve hours before the evaluation they were taken out to the ambient temperature (+22 °C).

2.3. Physicochemical analyses

Fruit masses, colour (in CIE L*a*b* scale, including chroma and hue angle), firmness (FF), soluble solid content (SSC), and titratable acidity (TA) were recorded each year of experiment. Thirty well shaped, vine ripened fruits were taken for each measurements. Just after harvest fruits were weighted. L* (lightness), a* (greenness [–] to redness [+]) and b* (blueness [–] to yellowness [+]) were determined using a spectrophotometer Minolta CM-508i (Konica Minolta Sensing Inc., Japan). The colour of each fruit was assessed separately for its background and blush colour (apart from those genotypes which have no blush). Firmness was determined by measuring compression using Instron 5542 penetrometer with a 4.5 mm diameter punch probe. Each fruit was subjected to a compression speed of 1 mm/s after contact and penetration to 10 mm, in approximate centre of the flat surface of the fruit. The firmness was expressed in Newton. Unlike other analyses, soluble solid content (SSC) and titratable acidity (TA) were measured in three replications, each for combined extract obtained from ten fruits. Abbe's refractometer was used to assess SSC in %. TA was measured by titrating with 0.1 N – sodium hydroxide (NaOH) to an endpoint of pH 8.1 and recalculated for anhydrous citric acid.

2.4. Sensory assessment

The method – quantitative descriptive analysis (QDA – Stone & Sidel, 1985) (sensory profiling) was applied for the detailed sensory characterization of hardy kiwifruit by the experienced panel at the Department of Vegetable and Medicinal Plants, WULS, consisting of 15 panellists trained according to ISO 3972 (1991) and ISO 8586-1 (1993). The panel was chosen for its experience in descriptive analysis of vegetables, fruits and spices. After screening assessors for allergic reactions to hardy kiwifruit, 11 panellists declaring consumption of

Table 1
Genotype used in the study and plants origin.

Genotype (origin)	Plant origin
Ananasnaya (<i>Actinidia arguta</i>)	Weihenstephan, Freising, Germany
Weiki (<i>A. arguta</i>)	Weihenstephan, Freising, Germany
Jumbo (<i>A. arguta</i>)	Fruits du Paradis, Switzerland
Geneva (<i>A. arguta</i>)	Fruits du Paradis, Switzerland
74-49 (<i>A. arguta</i>)	Fruits du Paradis, Switzerland
D11 ^a (<i>A. purpurea</i> × <i>A. arguta</i>)	Own selection, WULS
D14 ^a (<i>A. purpurea</i> × <i>A. arguta</i>)	Own selection, WULS
L1 ^a (<i>A. arguta</i>)	Own selection, WULS
M1 ^a (<i>A. arguta</i>)	Own selection, WULS

^abreeding code.

kiwifruit and willing to perform the study were chosen. Because the assessors were not experienced in assessment of hardy kiwi fruit, the evaluation procedure was established and trial assessment was performed in the year 2004, preceding the experiment. According to the QDA methodology, ISO 11035, 11035 (1994), a set of internal (texture and flavour) sensory attributes of the fruit was /INS; first individually selected, then discussed to ensure their common understanding, and finally defined by assessors during first session on three *Actinidia* genotypes. A precise procedure of fruit evaluation was established: fruit should be cut directly before the assessment; their cross-section should be smelled and odour attributes marked; the pulp should be tasted to evaluate its consistency and taste and flavour characteristics; fruit with skin should be tasted to mark the skin attributes. The following session on three different genotypes led to final corrections of sensory attributes and their evaluation sequence. Third session on nine *Actinidia* genotypes in 2004 was treated as the main training for analysis in the following years. The list of 17 selected texture and flavour descriptors, their anchoring points and precise definitions including references are presented in Table 2 (additionally kiwifruit and Granny Smith apple samples served during *Actinidia* odour evaluation as “sweet-nectar” and “cut grass” odour standards, respectively). The assessments were performed in the sensory laboratory fulfilling requirements of ISO 8589(1998) and equipped in data collection system ANALSENS NT. The samples consisting of three fruit of each genotype were individually coded and randomly presented to each panellist in plastic containers of 125 ml capacity to minimise any bias caused by presentation order. For each session, the evaluated fruit samples were randomly divided into two groups of four and five samples. Assessment of each group of genotypes was made in two replicates in one day interval in order to obtain over 20 scores for each of the attributes. Between samples, cool flat boiled water (of ambient temperature) and pieces of wheat roll were used as neutralizers. The intensity of attributes was scored on a 10 cm graphical continuous line scale from 0 to 10 with anchor terms given at both ends of the scale.

2.5. Statistical analysis of the data

All analyses were performed using Matlab ver. 6.5.0 (The Math-Works, Inc. 1998–2002) and XLSTAT ver. 7.5.2 (Addinsoft 1995–2004).

To check which physicochemical features and attributes of the evaluated *Actinidia* genotypes differed significantly, balanced one- (cultivar) and two-way (cultivar $\times$ year) analysis of variance (ANOVA) was applied. Tukey's Honestly Significant Difference (HSD) multiple

comparison procedure was used to compare physicochemical characteristics of fruit from various genotypes at the $p < 0.05$ significance level. Student's *t*-test was applied to test the season dependence of each cultivar physicochemical features.

Three-way balanced ANOVA (genotype $\times$ session $\times$ panellist) was used to check for the genotype dependence of the fruit sensory attribute values. The semantic differential chart plot was used to graphically present sensory profile of the examined fruit. The Principal Component Analysis (PCA) and Pearson correlations were used to describe the sensory pattern of *Actinidia* fruit and indicate main factors influencing its overall sensory quality. PCA, ANOVA and HSD ($p < 0.05$) procedures as well as the Agglomerative Hierarchical Clustering (AHC) method with the Euclidean (non-standardised) distance and Ward linkage, were performed in order to establish groups of genotypes with similar characteristics. As the choice of the number of clusters is somewhat subjective, and usually depends on common sense, we used the automatic truncation available in XLSTAT (at the point at which dissimilarity significantly decreased) and examined correctness of the obtained clusters using the silhouette plots obtained in Matlab.

3. Results

3.1. Postharvest physicochemical characteristics of hardy kiwifruit and its year-to-year variability

The physical (mass, and two shape indicators – length/width and width/depth proportions) and chemical (SSC, TA, and FF) characteristics of evaluated *Actinidia* genotypes of the examined fruit measured in both years are presented in Fig. 1. Each plot in Fig. 1 provides three pieces of information: first, it shows differences of the measured value between the genotypes; second, it indicates its inner genotypic variability; third, it presents year-to-year variability of the measured value for each genotype.

The results show high variability of the above characteristics between the fruit of the nine examined *Actinidia* genotypes. The *p*-values of the one-way ANOVA analysis (with genotypes as factor) in each of two consecutive years of the experiment are less than 0.001 for each of characteristics.

Apart from differences between the means of different genotypes, a very high variability within individual genotypes of such characteristics as firmness, mass and the width/depth proportion (for some genotypes) is represented by very high standard deviations of mean

Table 2
Fruit internal sensory attributes used in the presented Quantitative Descriptive Analysis.

Sensory attribute		Description	Anchoring points (left–right)
Odour/aroma	Sweet-nectar	Mild aroma of ripe kiwi fruit, nectar or acacia honey	None–very intensive
	Cut grass	Characteristic “green” odour of just cut lawn or Granny Smith apple	None–very intensive
	Acidic	Sharp, acidic odour, characteristic for unripe fruit (e.g. apple or plum)	None–very intensive
Pulp	Pulp consistency	Degree of firmness of fruit flesh	Firm–soft and juicy
Pulp taste/flavour/ chemestetic	Fruity, natural	Flavour characteristic for fully ripe kiwi or gooseberry fruits	None–very intensive
	Fruity, artificial	Flavour characteristic for kiwi-flavoured desert fruit gelee	None–very intensive
	Vinous	Flavour characteristic for overripe, slightly fermented kiwi fruit	None–very intensive
	Sweet	Basic taste evoked by sucrose or other sugars	None–very intensive
	Sour	Basic taste evoked by citric or malic acid	None–very intensive
	Bitter	Basic taste evoked by caffeine or quinine	None–very intensive
	Astringent	Perception of drying on the tongue surface (especially along the edges)	None–very intensive
Skin	Irritating	Perception of irritation in the throat after swallowing the sample	None–very intensive
	Skin resistance	Resistance of fruit skin when chewed	Firm, hard–soft, delicate
Skin taste/ chemestetic	Sour	Basic taste evoked by citric or malic acid	None–very intensive
	Bitter	Basic taste evoked by caffeine or quinine	None–very intensive
	Astringent	Perception of drying on the tongue surface (especially along the edges)	None–very intensive
	Irritating	Perception of irritation in the throat after swallowing the sample	None–very intensive

The abbreviation, description and anchoring points for each attribute given.

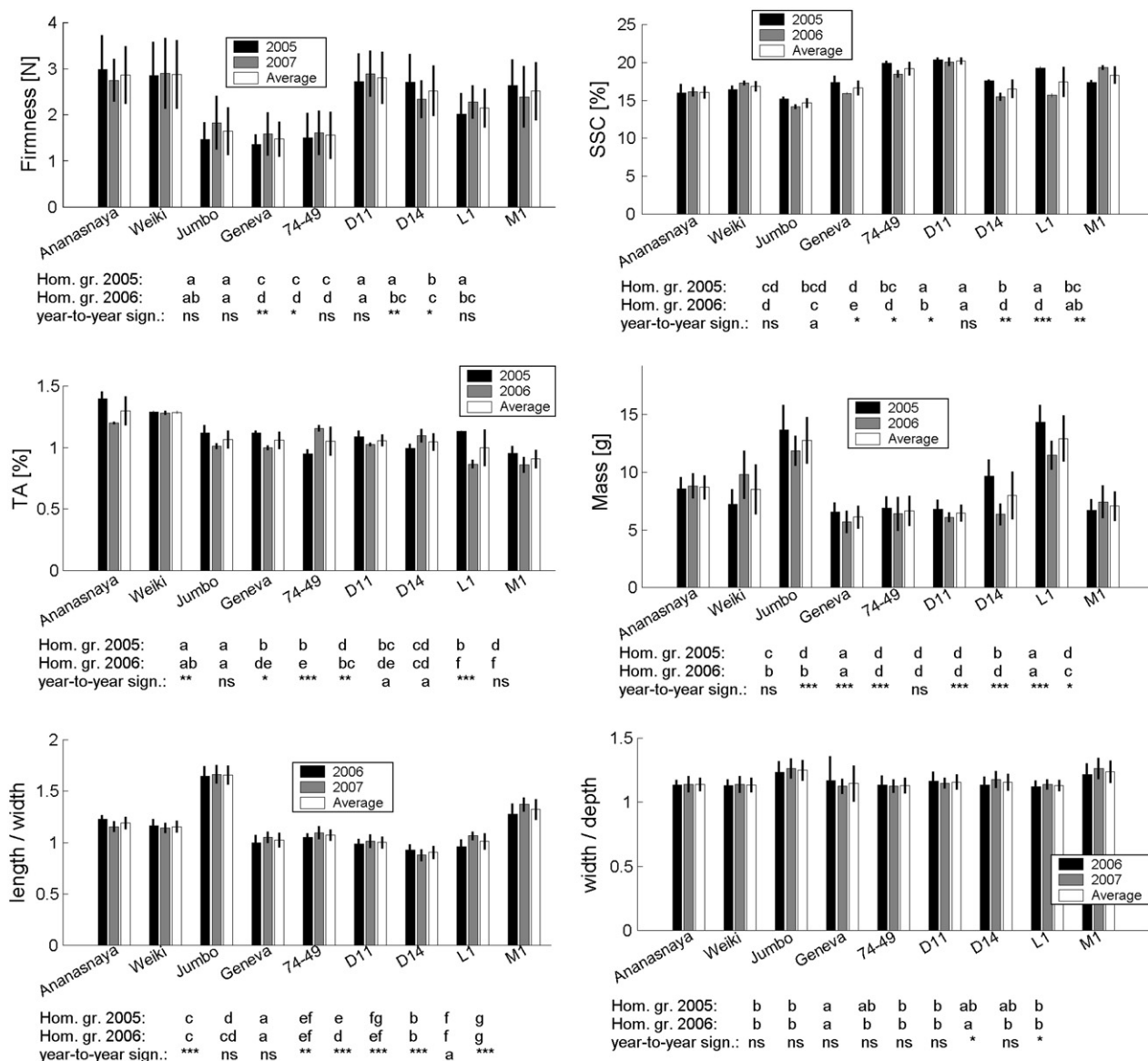


Fig. 1. Physiochemical postharvest characteristics of the fruit of the evaluated *Actinidia* genotypes: firmness, SSC, TA, masses, length/width, width/depth. For each genotype the following bars show values of the corresponding characteristics in the years 2005, 2006 and their average. The vertical lines represent the standard deviations of the masses in 2005 and 2006. Homogenous groups of genotypes in the years 2005 and 2006 and the significance of the t-Student test comparing the 2005 and 2006 values of each genotype given below the plots. ns = not significant, a = significant for $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

values of these features. The characteristics with lowest inner genotypic variability are SSC and the length/width proportion.

Average firmness of ripe fruit of various genotypes ranged from 1.36 to 3.31 N in the year 2005 and from 1.59 to 2.90 N in the year 2006. Three groups of genotypes can be distinguished. Genotypes 'Ananasnaya', 'Weiki' and 'D11' had the most firm fruit in both seasons. Genotypes 'D14', 'L1' and 'M1' are medium firm (tough 'M1' belongs to the firmest group in 2005). The less firm fruits were produced by genotypes 'Jumbo', 'Geneva' and '74-49'.

The SSC values varied from 14.2% to 20.3%. The highest SSC content was observed in both seasons in 'D11' fruit and lowest in 'Jumbo' fruit. Genotype '74-49' had very high content of SSC in both years. The hierarchy of remaining genotypes differed between the years 2005 and 2006.

The measured TA content ranged from 0.86% to 1.40% of citric acid. The highest TA quantity in both years was measured in 'Ananasnaya' and 'Weiki' fruit. The lowest values were observed in '74-49', 'D14' and 'M1' fruit in 2005 and in 'L1' and 'M1' fruit in 2006.

Actinidia has a distinguished petiole axis. This size related to this axis will be referred to as fruit length. The remaining sizes will be denoted as width and depth. The dimension of the *Actinidia* fruit is indicated by their mass which is significantly correlated with each of the fruit sizes: length, width and depth. One year mean masses range for various genotypes from 5.7 g ('Geneva') to 14.4 g ('Jumbo'). The examined genotypes may be divided into three groups basing on their size. The big ones – 'Jumbo' and 'L1', the medium ones – 'Ananasnaya' and 'Weiki', and the small ones – 'Geneva', '74-49' and 'D11'. The remaining 'D14' and 'M1' genotypes belong either into group of medium or small fruit depending on the year of observation.

A few different shapes of the tested *Actinidia* fruit can be distinguished. The width/depth proportion values presented in Fig. 1 are similar for all examined genotypes showing that all of them are slightly oblate in the cross section. The genotypes most oblate in both years of observations are 'Jumbo' and 'D14'. The differentiation of the fruit shapes is mostly due to the high range in the length/width proportion leading to separation of seven

(overlapping) homogenous groups of genotypes, see Fig. 1. 'Jumbo' and 'D14' are strongly elongated in the longitudinal section. 'Ananasnaya' and 'Weiki' are slightly elongated, 'Geneva', and '74–49', 'D11' and 'L1' are nearly circular. Finally, 'M1' is the only genotype oblate in the longitudinal section.

Strong variability of fruit characteristics between two years of experiment was observed in their SSC and TA content, masses and length/width proportion. P-values for the year dependence and genotype $\times$ year interaction in the two-way ANOVA analysis are less than 0.001 for all these characteristics. In the case of firmness and width/depth proportion no significant year dependence was observed. As the experiment covered only two years the conclusions drawn are rough but can indicate differences in stability of fruit characteristics between genotypes.

Genotypes with most significant variability of the SSC content are 'L1' and 'M1' and with no or low variability 'Ananasnaya', 'D11' and 'Weiki'. In the TA content case the highly variable genotypes are 'L1' and 'Geneva', followed by 'Ananasnaya' and '74–49'; the low variable ones are 'Weiki', 'D11', 'D14' and 'M1'. The highest year-to-year variability was observed for the mass and length/width proportion. In both cases six of nine genotypes showed highly significant ($p < 0.001$) difference between the mean results in the years 2005 and 2006. The genotypes with no significant mass difference were 'Ananasnaya' and '74–49' and with no difference in the length/width proportion 'Weiki' and 'Jumbo'.

Fruit colours represented in the $L^*a^*b^*$ scale are shown in Fig. 2 for background and Fig. 3 for blush colour, respectively. Figures show the location of the mean colour values for each genotype placed in the green–red/blue–yellow (a^*b^*) plane and separately on the luminosity (L^*) axis. The two-way ANOVA analysis (genotype $\times$ year) showed no significant difference of the L^* , a^* as well as chroma and hue angle values between the years 2005 and 2006 and the difference in b^* values at p-value equal to 0.024 for the background and 0.048 for the blush colours, respectively. Therefore, the results are presented for the mean values from two years of the experiment. In the case of genotypes having no distinct blush ('Jumbo') or background ('D11') colour the same colour has been presented in Figs. 2 and 3. The chroma and hue angle values and their homogenous groups for the combined two year data are presented in Table 3.

For the purpose of comparison of fruit colours the ranges of standard deviations of the L^* , a^* and b^* values are plotted for each genotype as the ellipses in the a^*b^* plane and lines in the L^* axis. The ellipses can be compared with the size of the JND circles representing the range of the "just noticeable difference" between two colours represented in the a^*b^* plane (Sharma, 2003). Two points in the a^*b^* plane lying in the distance higher than the radius of the JND circle will be recognised by a human eye as representing distinguishable colours.

Results presented in Table 3 shows that two groups of genotypes with similar background colour can be separated. First of them consists of 'Jumbo', '74–49' and 'M1'. Second group includes 'Ananasnaya', 'Geneva', 'L1' and 'M1'. As can be seen in Fig. 2 mean colours of fruit belonging to both these groups overlap (apart from 'L1' which has the smallest colour dispersion) and therefore for many fruits they can be indistinguishable. Genotypes which fruit background colour differs from other genotypes are 'Weiki' and 'D14'. Background colour of all genotypes apart from 'D11', which can be easily distinguished from other genotypes as its fruit is totally rose-red, varies from light- to dark-green.

Stronger separation of blush colour of various genotypes in comparison to the background colour case can be observed in Fig. 3. According to results presented in Table 3 two groups of genotypes with similar blush colour can be distinguished. First group consists of 'Ananasnaya', 'Weiki' and 'D14' characterised with cherry to rose-red blush. Second group includes 'L1' and 'M1' with very light brown-green (rarely reddish) blush colour. The fruit of '74–49' may have slight earth-yellow and fruit of 'Geneva' may have slight red-brown blush. Finally, the fruit of 'Jumbo' has no blush colour.

The pulp colour of the fruit of all other genotypes apart from 'D11' is green or yellow-green (not shown). The inner colour of 'D11' fruit is rose-red.

3.2. Postharvest sensory characteristics of hardy kiwifruit and its year-to-year variability

The general sensory profile of the hardy kiwifruit is graphically presented in Fig. 4, showing the variability and ranges of the average sensory attribute values for the examined nine representatives of the species in two years. As can be noticed the lines corresponding to different genotypes are parallel between most of the attribute ratings indicating that there are no strong differences between overall characteristics of genotypes. According to Fig. 4, hardy kiwifruit is characterised with soft, sour and averagely astringent skin with additional irritating note. The taste of the soft, jelly-like pulp is dominated by fruity and sweet tastes with low admixture of irritating, vinous, astringent and sour tastes. In both skin and pulp cases, the bitter taste is the least detectable. Finally, the "sour odour", "odour of cut grass" and "sweet-nectar aroma" can be identified but not on a high level. The results show also that the skin of hardy kiwifruit has generally bitterer, more astringent and irritating taste than the fruit pulp.

As presented in Table 4, the attributes according to which genotypes differ most strongly are the "sweet-nectar odour", "sweet pulp taste", "sour skin taste", "fruity artificial pulp flavour" and "pulp consistency". Results obtained for "bitter pulp taste", "acidic odour", "fruity natural", "vinous pulp flavour" as well as "irritating" skin perception did not differ significantly for the examined genotypes showing to have no power to discriminate them.

The relationships between sensory attributes were examined using attribute correlations and PCA plots and are presented in Fig. 5 (for each genotype the results of 2005 and 2006 were treated as separate observations).

The sensory attributes were divided into three groups basing on their mutual correlations. It was noticed that these groups form two axes within the PCA plot in Fig. 5. The first axis is related with two groups of attributes: astringent-irritating stimuli and the consistency attributes. The second axis is related with the sweet stimuli group: "sweet-nectar odour" and "pulp sweet taste". The largest, astringent-irritating stimuli group contains: both skin and pulp "irritating" and "astringent" notes, "skin bitter taste", "acidic odour" and "odour of cut grass". Most of the above attributes are negatively correlated with the "skin resistance". Moreover, "acidic odour" and "odour of cut grass" form one group with the skin and pulp "sour taste". The set of consistency attributes consists of "skin resistance", "pulp consistency" and "pulp vinous flavour". Most of the attributes belonging to each of the presented groups are significantly correlated at $p < 0.05$ or $p < 0.1$. The third Principal Component (figure not shown) separates the attributes belonging to the astringent-irritating stimuli group and the sour tastes as well as attributes from the sweet stimuli group and the "pulp fruity artificial flavour".

The year-to-year differences between the mean values of the sensory attributes were also observed. In general fruits collected in 2006 were characterised with higher intensity of attributes related with the astringent-irritating stimuli: "acidic odour" and "odour of cut grass", both skin and pulp "irritating" and "astringent" notes and "sour taste". On the other hand, most of genotypes had higher "pulp artificial fruity flavour" and "sweet-nectar odour" intensity in 2006 in comparison to 2005.

Concerning individual genotypes it can be noticed that intensity of sensory attributes changed strongly between the years of the experiment. In order to identify attributes which can be attached to each tested genotype we examine clusters of genotypes obtained for the combined 2005–2006 sensory data. Fig. 5 indicates that the most stable under variation of climatic conditions are hybrids 'D11' and 'D14' (both hard, with high astringent-irritating values) and 'Geneva'

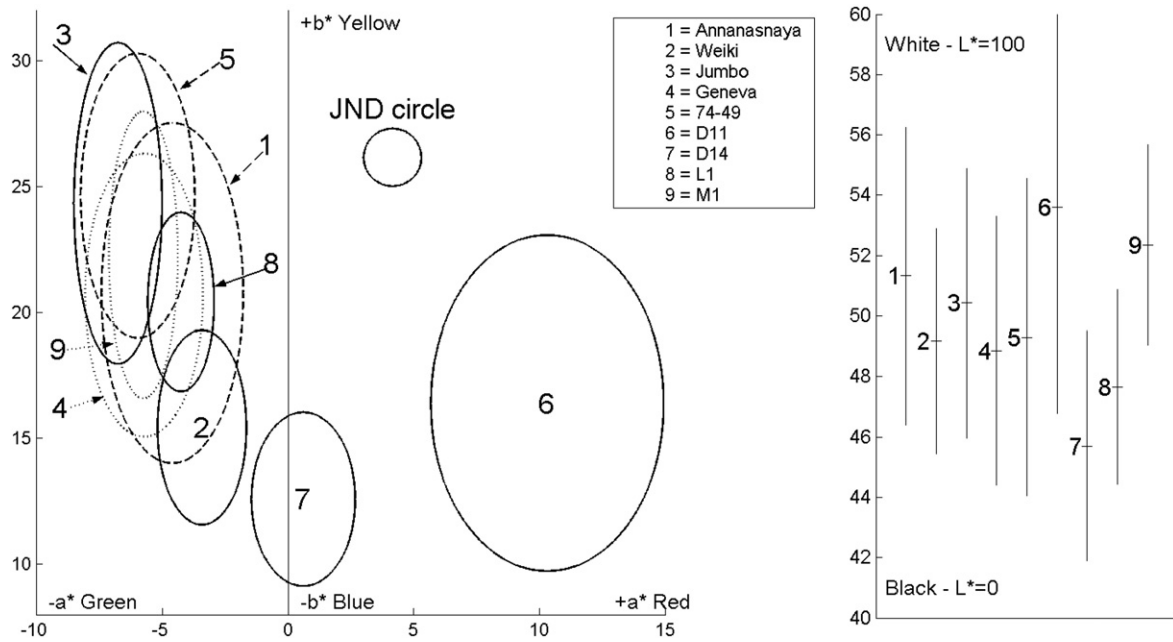


Fig. 2. Background colour of the fruit of the evaluated *Actinidia* genotypes in the $L^*a^*b^*$ scale. The results are presented for the mean values from two years of the experiment. The ellipses in the left plot are centred at the mean values of the a^* and b^* for each genotype and their sizes correspond to the standard deviations of a^* and b^* . The JND circle represents the range of the "just noticeable difference" between two colours represented in the a^*b^* plane. The right plot shows the means and standard deviation ranges of the L^* for each genotype.

(soft, with low astringent-irritating values). 'Annanasnaya', 'Weiki', and 'M1' belong to two clusters, which lie along the "sweet" axis. They all are sweeter in 2006 than in 2005 but have relatively stable, average values of the astringent-irritating and consistency attributes. Therefore, it can be concluded that these genotypes have similar sensory features. 'L1' changed its characteristics along the "astringent-irritating-consistency" axis becoming softer and with lower astringent-irritating stimuli values in 2005 than in 2006. The characteristics of the remaining 'Jumbo' and '74-49' genotypes are not stable when either group of attributes is considered.

3.3. Relationship between physicochemical characteristics and sensory attributes of hardy kiwifruit

Apart from the evaluation of postharvest physicochemical and sensory characteristics of the examined *Actinidia* genotypes their possible relations were investigated.

Fruit firmness was in both years significantly ($p < 0.05$) correlated with "sour pulp taste" but the correlations were contradictory because of their opposite signs — positive in 2005 and negative in 2006. Still, the concordant, negative correlation of firmness with "skin sour taste" was

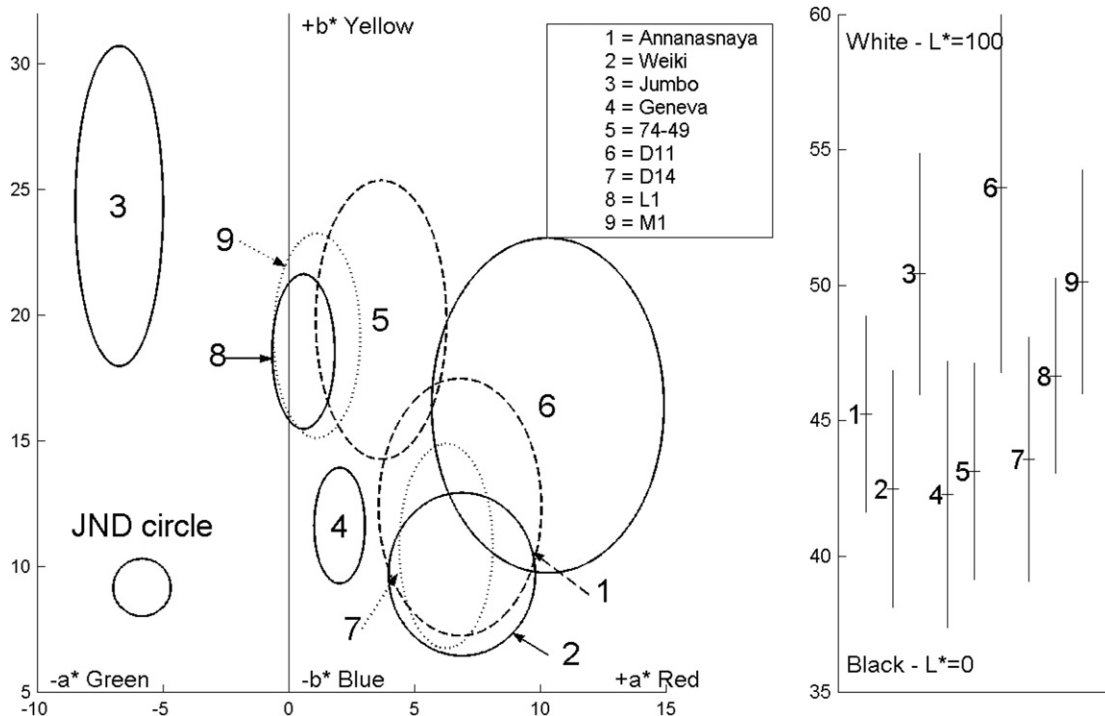


Fig. 3. Same as Fig. 2, for the blush colour of the fruit of the evaluated *Actinidia* genotypes.

Table 3
The mean chroma and hue angle values for the background and blush colours of the examined *Actinidia* genotypes for the combined data from years 2005 and 2006 and their homogenous groups (denoted by letters).

		Anna	Weiki	Jumbo	Geneva	74–49	D11	D14	L1	M1
Background colour	Chroma	21.4b	15.9c	25.3a	21.5b	25.4a	xxx	12.7d	20.9b	23.0ab
	Hue angle	101.4a	102.2a	105.6a	105.0a	103.6a	xxx	86.2b	101.7a	104.9a
Blush colour	Chroma	14.6b	12.3bc	xxx	11.8c	20.3a	20.6a	13.0bc	18.6a	19.3a
	Hue angle	59.5d	54.0 d	xxx	80.1bc	79.9c	54.8d	58.2d	88.2a	86.2ab

observed in both years (-0.37 in 2005 and -0.88 in 2006), though it was significant ($p < 0.01$) only in 2006. Firmness was also negatively correlated with attributes from the sweet stimuli group: “sweet pulp taste” and “sweet-nectar odour”, but the correlations were significant at $p < 0.05$ only in the year 2005 (-0.70 and -0.67 , respectively). Interestingly, firmness measured mechanically was not significantly correlated with main consistency attributes “skin resistance” and “pulp consistency” though in both cases correlation coefficients were negative as could be expected (both attributes were defined with ‘firm’ as left anchoring point). Moreover, negative correlation of firmness and “vinous pulp flavour”

attribute was observed in both years (-0.78 and -0.50 , respectively), significant at $p < 0.05$ in 2005.

“Sweet pulp taste” was in both years negatively correlated with TA (-0.76 and -0.05), positively with SSC (0.60 and 0.50) and the SSC/TA proportion (0.75 and 0.34) but again the correlations were significant (at $p < 0.05$ for TA and SSC/TA and at $p < 0.1$ for SSC) only in the year 2005. On contrary “sour pulp taste” was positively correlated with TA (0.78 and 0.39) and negatively with SSC (-0.25 and -0.33) and SSC/TA proportion (-0.58 and -0.55) but this time only the correlation with TA in 2005 was significant at $p < 0.05$ and with SSC/TA

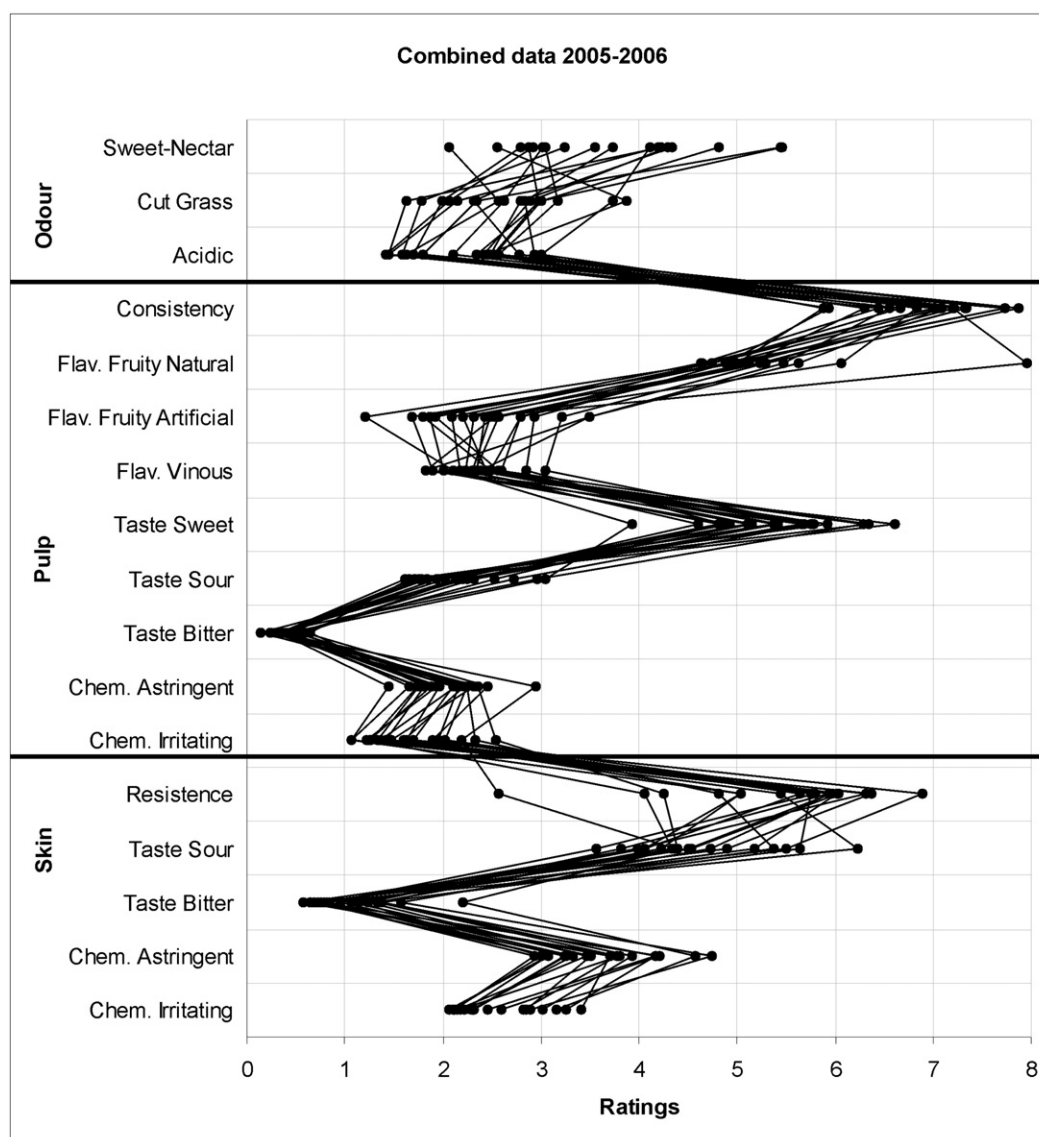
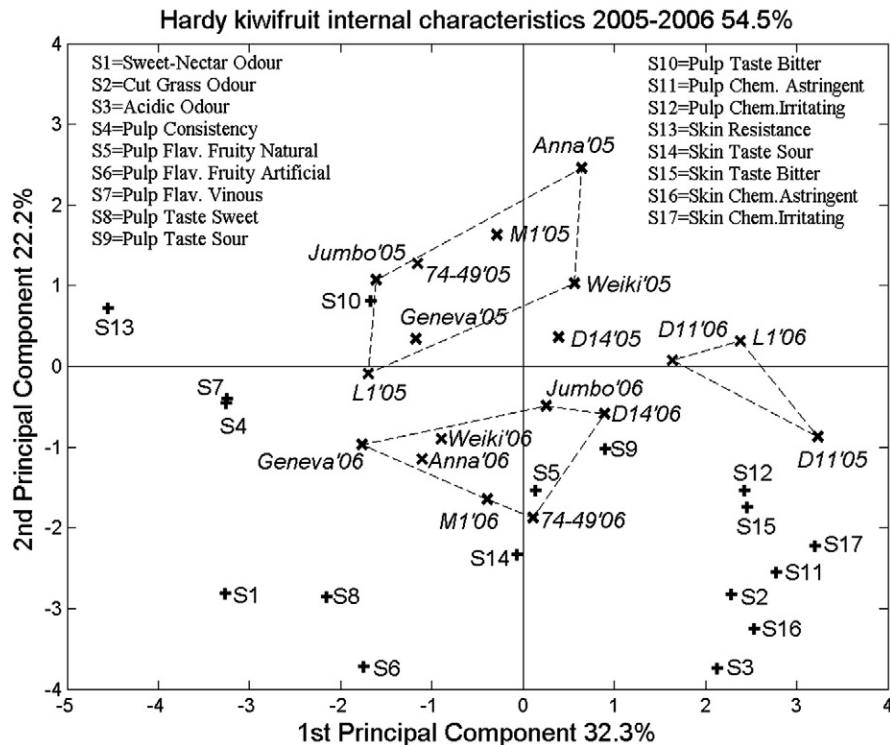


Fig. 4. The semantic differential chart presenting sensory profiles of the analysed genotypes over two years of the experiment.

Table 4

Significance of the attribute differences among genotypes and their homogenous groups (denoted by letters) in each year of the experiment according to the three-way ANOVA.

Sensory attribute		Year	Sign	Anna	Weiki	Jumbo	Geneva	74–49	D11	D14	L1	M1
Odour/aroma	Sweet-nectar	2005	***	2.06a	3.02ab	4.23c	4.19c	3.24bc	2.88ab	2.79ab	5.44d	2.92ab
		2006	***	5.46d	4.81cd	3.05ab	4.34bcd	4.11bc	3.73abc	3.55abc	2.56a	4.29bcd
	Cut grass	2005	*	2.57bcd	2.63cd	1.63a	2.15abc	1.78ab	2.98d	1.99abc	2.34abcd	2.07abc
		2006	a	3.00abc	3.01abc	3.17abc	2.79ab	3.74bc	2.83ab	2.31a	3.88c	2.89abc
Pulp texture	Acidic	2005	ns	1.63a	2.10ab	1.44a	1.44a	1.59a	2.51b	1.70ab	1.80ab	1.42a
		2006	ns	2.52a	2.34a	2.57a	2.48a	3.00a	2.93a	2.78a	2.44a	2.42a
	Pulp consistency	2005	**	6.66abc	7.09bcd	7.73d	7.02abcd	6.44ab	6.30a	7.20cd	7.33cd	7.01abcd
		2006	***	7.21bc	7.08bc	7.73c	7.87c	6.83b	5.88a	7.34bc	5.94a	6.55ab
Pulp taste/flavour/irritation	Fruity. natural	2005	ns	4.74	4.88	4.96	4.64	5.12	7.96	5.27	4.74	
		2006	ns	5.09ab	5.63ab	4.90a	5.29ab	6.06b	4.99ab	5.24ab	4.89a	5.47ab
	Fruity. artificial	2005	*	1.20a	2.32bc	1.79ab	2.79c	1.92abc	2.52bc	2.43bc	2.57bc	2.09abc
		2006	*	2.79abcd	3.49d	2.94bcd	3.21cd	2.48abcd	1.69a	2.21abc	1.87ab	3.49d
	Vinous	2005	ns	2.10	2.23	2.49	2.49	2.57	1.82	2.35	2.33	2.18
		2006	ns	2.60ab	2.38ab	2.85ab	3.05b	2.30ab	1.90a	2.44ab	2.00ab	1.82a
	Sweet	2005	***	3.93a	4.60ab	5.78cd	5.42bcd	6.34d	5.65cd	5.38bcd	5.92cd	5.11bc
		2006	*	5.42ab	5.68abc	4.85a	5.76abc	6.29bc	4.92a	5.15a	4.81a	6.61c
	Sour	2005	**	3.04b	2.14a	1.66a	1.77a	1.62a	2.24a	1.76a	1.71a	1.84a
		2006	ns	2.32abc	2.17abc	2.53abc	2.72bc	2.96c	1.94ab	2.21abc	2.02ab	1.78a
	Bitter	2005	ns	0.42	0.35	0.64	0.37	0.34	0.30	0.45	0.33	0.34
		2006	ns	0.51ab	0.59b	0.50ab	0.29ab	0.24ab	0.37ab	0.14a	0.34ab	0.39ab
	Astringent	2005	**	1.97ab	2.22bc	1.81ab	1.75ab	1.44a	2.95c	1.65ab	1.74ab	1.93ab
		2006	ns	2.25a	2.46a	2.16a	2.11a	2.13a	1.88a	2.25a	2.36a	2.31a
	Irritating	2005	*	1.63ab	1.60ab	1.42a	1.34a	1.07a	2.19b	1.07a	1.26a	1.22a
		2006	ns	2.02abc	1.90abc	1.95abc	1.70abc	1.36ab	1.25a	2.33bc	2.54c	1.47ab
Skin	Skin resistance	2005	***	5.96c	5.04b	6.31c	6.02c	6.37c	2.57a	5.04b	5.80bc	5.94c
		2006	***	6.04cd	5.64bc	5.76bc	6.89d	5.44bc	4.05a	4.82ab	4.25a	5.95cd
Skin Taste/Irritation	Sour	2005	*	4.51bcd	4.05abc	3.99ab	5.18d	4.90cd	4.37abcd	4.23abc	3.57a	3.82ab
		2006	***	4.54abc	4.06a	5.64de	5.50cde	6.23e	4.34ab	5.38bcde	4.39ab	4.73abcd
	Bitter	2005	***	0.73a	0.81a	0.78a	0.95a	0.69a	2.20b	1.33a	0.84a	1.24a
		2006	ns	1.07ab	1.14ab	1.35ab	0.64a	0.76a	1.34ab	1.38ab	0.58a	1.57b
	Astringent	2005	*	2.93a	3.26a	3.24a	3.33a	3.08a	4.57b	3.77ab	3.07a	3.46a
		2006	ns	3.51ab	3.01a	3.93abc	3.80abc	4.21bc	4.17bc	4.17bc	3.70abc	4.75c
	Irritating	2005	ns	2.12a	2.31ab	2.30ab	2.29ab	2.06a	3.16b	2.82ab	2.22a	2.15a
		2006	ns	2.85	2.10	3.02	2.18	2.59	2.45	3.26	3.41	2.89

ns = not significant, a = significant for $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. The remaining factors in the ANOVA were the panellist and the evaluation session.**Fig. 5.** The PCA biplot of sensory profiles of the evaluated *Actinidia* genotypes based on first and second principal components. Plots obtained for the combined data from years 2005 and 2006. The clusters of genotypes based on their sensory characteristics are represented with the convex hulls containing all genotypes belonging to each cluster.

in both years at $p < 0.1$. Additionally, two other astringent-irritating stimuli were negatively correlated with the SSC: “bitter pulp taste” (-0.72 at $p < 0.05$ in 2005) and “irritating pulp chemesthetic” (-0.78 at $p < 0.05$ in 2006). Finally, two of the consistency group attributes were in both years negatively correlated with the SSC and the SSC/TA proportion. For “pulp consistency” the correlations with these characteristics were: -0.63 (at $p < 0.1$) and -0.40 (non-significant) in 2005 and -0.63 and -0.66 (both at $p < 0.1$) in 2006. For “pulp vinous flavour” the corresponding correlations were: -0.21 and -0.09 (both non-significant) in 2005 and -0.71 and -0.74 (both at $p < 0.05$) in 2006.

4. Discussion

Vine ripe hardy kiwifruit are characterised with high variability of the examined postharvest physicochemical characteristics: firmness, TA, SSC, mass, shape and external colour. The variability is observed between the fruits of individual genotypes, among different genotypes as well as in two years of the experiment. On contrary, the sensory evaluation indicates that there are no strong differences between overall sensory features of the examined genotypes. Still, important year-to-year difference in sensory characteristics of the fruit was observed. The variability of sensory features of individual genotypes was not studied.

The inner genotypic variability of physicochemical characteristics can be related to many factors. Firstly, ripening of hardy kiwifruit is very rapid and not uniform on the shrub. Moreover, the time period in which *A. arguta* fruit preserves acceptable firmness is very short in comparison to other *Actinidia* species (White, Nichal de Salva, Requeiro-Tapia, & Harker, 2005). These factors may explain very high diversity of fruit firmness as well as variability of their SSC and TA content within individual genotypes. Such variability could be limited by establishing strict method to precisely determine hardy kiwifruit maturity. Unfortunately, unlike in the case of other fruit, which have been present on the market for a long time (like kiwifruit), no such procedure has been elaborated so far. The only studies concerning the dependence of *A. arguta* fruit sensory characteristics on their maturity focused on the ‘Ananasnaya’ cultivar (Fisk et al., 2006, 2008). Therefore, in this study the choice of the harvest date of fruit at their eating ripeness stage was based mainly on the tactile observation of fruit softness.

Among factors which may influence inner genotypic variability of fruit masses the most important is the pollinator's activity being crucial in the case of dioecious plants. Different pollination effectiveness may be caused by flower position in an inflorescence and on a shrub as well as by weather conditions.

In the case of fruit colours, their diversity within individual genotypes can be again explained with different positions of fruits in an inflorescence and on a shrub leading to different levels of their shading and hence different levels of insolation.

The variability in examined postharvest physicochemical characteristics among genotypes is predominantly subject to their genetic differences. In some cases genotypes can be separated into groups of similar features. First, genotypes divide into those of high, medium and low firmness with the possible over twofold span of firmness values. Next, the exploiting fact that the mass of the examined fruit is an indicator of their size, genotypes can be divided into groups of small, medium and big fruit. Mean mass of the biggest genotype is nearly three times greater than the mass of the smallest one. Moreover, the length/width proportions show that the longitudinal section of fruit of various genotypes is strongly or slightly elongated, nearly circular or oblate. Finally, the main diversity among the genotypes in their background colour is due to the *A. arguta* and *A. purpurea* hybrids. While the background colour of all pure *A. arguta* genotypes varies smoothly from light- to dark-green, colour of ‘D14’

hybrid is a mixture of green and red components and ‘D11’ is totally pink-red.

The fact that the skin of *A. arguta* fruit and its hybrid with *A. purpurea* is edible can be both advantageous and disadvantageous. The presented results show that the skin of hardy kiwifruit has generally bitterer, more astringent and irritating taste than their pulp. On the one hand, according to the Kim, Beppu, & Kataoka (2009) observation that the concentration of phenolics was 15 times as high in *A. arguta* fruit skin as in their pulp, these tastes can be strongly correlated with the phenolic content. Therefore, edible skin of hardy kiwifruit can significantly contribute to the fruit pro-healthy features. On the other hand, these negative tastes may reduce fruit attractiveness. However, as observed by Amos (2007) the differences in intensity of bitterness and sweetness between peeled and unpeeled *A. arguta* fruit and the peel itself were not as big as the ones for large fruit and the sensory characteristics associated with the skin of *A. arguta* fruit had similar impacts on fruit palatability as observed for other types of small fruits. Apart from that astringency and bitterness probably can be reduced when fruit accumulates higher amount of sucrose but the level of the reduction depends on the type, structure and concentration of phenolics (Ares, Barreiro, Deliza, & Gambaro, 2009). Finally, the required chewing force required for *A. arguta* fruit consumption is only slightly higher than in the case of other fruit of similar size (Amos, 2007).

Three main groups of the tested *Actinidia* fruit sensory attributes linked with each other can be distinguished basing on their correlations. The astringent-irritating stimuli group and the consistency group are negatively correlated showing that fruit with softer skin have less astringent-irritating taste. According to the lack of correlations of the above attributes with the sweet stimuli, which can be seen in Fig. 5, where the two above groups of attributes form a nearly perpendicular axis to the “sweet-nectar odour” and “pulp sweet taste” vectors in the PCA plot, they seem to have lesser impact on fruit sweetness sensation.

In the last, year-to-year variability case, the statistically significant influence of the season on fruit characteristics was observed in all measured physicochemical characteristics apart from firmness and width/depth proportion, for which very high inner genotypic fruit diversity was seen. Similarly as it is the case of many other plants, such characteristics of *A. arguta* fruit as firmness, SSC, TA and mean masses can be strongly modified by weather conditions during the plant growth and flowering periods and especially during the fruit ripening phase (Moretti, Mattos, Calbo, & Sargent, 2010). Such variability of SSC and firmness in the vine ripe hardy kiwifruit of different genotypes and in different years was observed by Hassal, Pringle, & MacRae (1998). It was also noticed by Strik & Hummer (2006) for SSC in ‘Ananasnaya’. Very strong inner genotypic variability of both, background and blush colours of the examined fruits were observed in each season and therefore no significant year-to-year differences were noticed. Still, it may be assumed that different number of sunny days in the fruit ripening stage and fruit sun exposure may influence their colours, especially the blush tint.

Year-to-year difference in postharvest sensory characteristics of the examined fruit was also observed. In general fruit collected in 2006 were characterised with higher intensity of “pulp artificial fruity flavour” and “sweet-nectar odour” attributes as well as the astringent-irritating stimuli in comparison to 2005.

Relationships between physicochemical characteristics and sensory attributes of the examined hardy kiwifruit may indicate importance of the physicochemical measurements in estimating fruit sensory features. Still, as the data from only two years of measurements were studied, the presented conclusions are very rough. The results show that firmness measured via mechanical method may be used to rate “skin sour taste”, “sweet pulp taste” and “sweet-nectar odour”. Less firm fruits have higher values of these attributes. On the other hand, mechanical firmness does not seem to correspond exactly to the sensory sensations

of skin and pulp firmness (assessed via “skin resistance” and “pulp consistency” attributes).

As could be expected, SSC, TA and their SSC/TA proportion are related to the “sweet and sour pulp tastes”. Moreover, results of the study indicate correspondence between high SSC values and low values of pulp astringent-irritating stimuli (and vice-versa). Finally, the pulp consistency attributes (including “pulp consistency” and “pulp vinous flavour”) are negatively correlated with the SSC and SSC/TA values. No relationship between the physicochemical characteristics and skin sensory attributes was observed.

5. Conclusions

High diversity of postharvest physicochemical characteristics of the fruit of various hardy kiwifruit genotypes may be of high importance for their popularisation among the consumers. The possible choice allows consumers to select fruit satisfying their individual preferences.

This fruit diversity is significantly increased by the *A. arguta* and *A. purpurea* hybrids which are responsible for large part of the colour differences among the genotypes, revealing high potential of cross-breeding of these species. As the hybrids do not differ from the *A. arguta* genotypes in overall sensory characteristics, which are similar for all examined genotypes, the consumers should treat them as an additional extension of the hardy kiwifruit offer.

The year-to-year variability of fruit postharvest characteristics may be limited by better hardy kiwifruit cultivation, especially irrigation or trimming, schemes. Artificial methods to boost fruit maturation at low sun exposure may be also important as such weather conditions during fruit ripening period seem to reduce final fruit sensory values.

Supplementary materials related to this article can be found online at doi:10.1016/j.foodres.2011.01.033.

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