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Assessment of food safety of peach (*Prunus persica* (L.) Batsch) cultivars by fruit pH and nitrate content

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Оценка пищевой безопасности сортов персика (*Prunus persica* (L.) Batsch) по величине pH и содержанию нитратов в плодах

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Abstract

The aim of this study was to determine the active acidity (pH) and nitrate content of peach fruits of cultivars grown in the Fergana region and to assess their food safety. The experiment was carried out in 2022–2024 in the Uzbekistan district on nine cultivars (control — Elberta) in four replications, giving 108 observations. Fruit pH was measured potentiometrically and nitrate content ionometrically; the data were processed by two-way analysis of variance (cultivar × year). Flesh pH ranged from 3.69 (Lola) to 4.17 (Caldesi 2000), averaging 3.96 (LSD05 = 0.08), and nitrate content ranged from 37.8 (Elberta, Lola) to 40.7 mg/kg (Caldesi 2000), averaging 39.1 mg/kg (LSD05 = 1.3 mg/kg). The effect of cultivar was significant for both traits (F = 29.9 for pH and F = 5.68 for nitrate at F05 = 2.06), whereas the effects of year and of the cultivar × year interaction were not significant, so the cultivar differences were stable over the three years. In all cultivars the nitrate content was below the maximum permissible level (MPL = 60 mg/kg), amounting to 62.9–67.8 % of it. A very weak positive correlation was found between pH and nitrate content (r = 0.208; n =

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108; p = 0.031). Risk assessment showed that a daily intake of 0.2 kg of fruit provides 3.4–3.7 % of the acceptable daily intake (ADI = 3.7 mg/kg body weight), with HQ < 1. Since pH was below 4.5 in all samples, pasteurization regimes may be used for processing.

Аннотация

Целью исследования являлось определение активной кислотности (pH) и содержания нитратов в плодах сортов персика, выращиваемых в условиях Ферганской области, и оценка на этой основе пищевой безопасности продукции. Опыт проводился в 2022–2024 гг. в Узбекистанском районе на девяти сортах, включая контрольный сорт Эльберта, в четырёхкратной повторности; проанализировано 108 наблюдений. Величину pH определяли потенциометрически, содержание нитратов — ионометрически; данные обработаны методом двухфакторного дисперсионного анализа (сорт × год). Величина pH мякоти в разрезе сортов изменялась от 3,69 (Лола) до 4,17 (Кальдези 2000), составив в среднем 3,96 (НСР05 = 0,08), содержание нитратов — от 37,8 (Эльберта, Лола) до 40,7 мг/кг (Кальдези 2000), в среднем 39,1 мг/кг (НСР05 = 1,3 мг/кг). Дисперсионный анализ показал достоверное влияние фактора «сорт» по обоим показателям (F = 29,9 для pH и F = 5,68 для нитратов при F05 = 2,06), тогда как влияние фактора «год» и взаимодействия факторов оказалось недостоверным, то есть сортовые различия были устойчивы в течение трёх лет. У всех сортов содержание нитратов было ниже предельно допустимой концентрации (ПДК = 60 мг/кг) и составляло 62,9–67,8 % от неё. Между pH и содержанием нитратов выявлена очень слабая положительная связь (r = 0,208; n = 108; p = 0,031). Оценка риска показала, что при суточном потреблении 0,2 кг плодов поступление нитратов составляет лишь 3,4–3,7 % допустимой суточной дозы (ADI = 3,7 мг/кг массы тела) при HQ < 1. Поскольку во всех образцах pH был ниже 4,5, при переработке плодов применимы режимы пастеризации.

Keywords: peach, active acidity, pH, nitrate, food safety, maximum permissible level, analysis of variance, cultivar, Fergana region.

Ключевые слова: персик, активная кислотность, pH, нитраты, пищевая безопасность, ПДК, дисперсионный анализ, сорт, Ферганская область.

Introduction

Peach (*Prunus persica* (L.) Batsch) is a stone fruit crop widely grown in Uzbekistan, in particular in the Fergana Valley, and a considerable share of the produce is directed to the domestic market and to export [8]. In recent years the requirements imposed on fruit have no longer been limited to taste and marketable quality: they are also defined by the ecological cleanliness and food safety of the produce, since a consignment that fails to meet the established limits is withdrawn from trade on export markets [3].

Nitrates (NO_3^-) are a natural intermediate product of nitrogen metabolism in plants. In the human body they can be converted into nitrites and further into nitrosamines, while nitrites convert haemoglobin into methaemoglobin and impair oxygen transport [5]. For this reason the European Food Safety Authority (EFSA) has set an acceptable daily intake (ADI) for nitrate of 3.7 mg/kg body weight per day [1], whereas the sanitary standards in force establish a maximum permissible

level (MPL) of 60 mg/kg for stone fruits. According to a worldwide meta-analysis, the mean nitrate content of fruits is 44.02 mg/kg, about ten times lower than that of vegetables (438.31 mg/kg) [2]; nevertheless, this indicator varies considerably depending on the cultivar and on the rate of nitrogen fertilization [4; 10].

The active acidity (pH) of the fruit is the second indicator linking quality and safety. Besides determining the sugar–acid balance of the taste, it also governs microbiological stability: at a pH below 4.6 *Clostridium botulinum* does not grow, so such products are classified as «high-acid» foods and pasteurization is applied instead of sterilization during canning [9]. In peach, acidity is determined mainly by malic and citric acids [7]. In the literature the pH of peach has been studied extensively from the standpoint of taste quality [6], whereas nitrate has been examined mainly in vegetables; studies evaluating both indicators together for locally grown cultivars are almost absent. This defines the novelty of the present work: using nine peach cultivars grown in the Fergana region as an example, the variability of pH and nitrate content was assessed by analysis of variance with respect to the cultivar and the year factors, the relationship between the two indicators was established, and the results were interpreted quantitatively by means of the internationally accepted risk assessment algorithm.

The aim of the study was to determine the pH and the nitrate content of the fruits of peach cultivars grown under the conditions of the Fergana region, to assess the relationship between these indicators and to substantiate the compliance of the produce with food safety requirements.

Materials and Methods

The study was carried out in 2022–2024 in a peach orchard in the Uzbekistan district of the Fergana region. The objects of study were nine peach cultivars: Champion, Elberta (control), Extreme 514, Vostok, Lola, Super lola, Oq luchchak, Big Top and Caldesi 2000. All cultivars were grown on trees of the same age and under the same agronomic background, with identical irrigation and fertilization regimes, which made it possible to isolate the effect of the cultivar factor. The experiment was laid out in four replications; over the three years a total of 108 observations (9 cultivars × 3 years × 4 replications) were obtained for each indicator.

Fruits of each cultivar were sampled at the stage of consumer ripeness. In each replication, fruits were picked from five typical trees, from four sides of the canopy, and an average sample of 3 kg was formed. The analyses were performed on the day of sampling, in a homogenate of the fruit flesh (without the stone).

The active acidity of the flesh was measured potentiometrically with a digital pH meter fitted with a glass electrode at 20 ± 1 °C; before each series of measurements the instrument was calibrated against buffer solutions of pH 4.01 and pH 6.86. The content of nitrate ions (NO_3^-) was determined ionometrically with an ion-selective (nitrate) electrode: a 10 g portion of the homogenate was extracted with a 1 % solution of potassium aluminium sulphate, and the result was calculated from a calibration curve and expressed in mg/kg of fresh fruit weight.

The results were processed by two-way analysis of variance (factor A — cultivar, factor B — year) following the method of Dospekhov [11]. The error variance was calculated at 78 degrees of freedom; for each cultivar the mean and its standard error (M ± m), the least significant difference

at the 5 % level (LSD05) and the accuracy of the experiment (Sx, %) were obtained, while the variability among cultivars was assessed by the coefficient of variation (V, %). The relationship between pH and nitrate content was evaluated by the Pearson correlation coefficient (r).

The estimated daily intake of nitrate was calculated as EDI = (C × IR) / BW, where C is the nitrate concentration, mg/kg; IR is the daily consumption, kg; and BW is the body weight, kg. The value obtained was compared with the ADI of 3.7 mg/kg body weight per day established by EFSA, and the hazard quotient was calculated as HQ = EDI / ADI [1; 2].

Results and Discussion

Active acidity (pH) of the fruit. Averaged over the three years, the pH of the fruit flesh varied among cultivars from 3.69 to 4.17, with a mean value of 3.96 (Table 1). The analysis of variance showed a highly significant effect of the cultivar factor (F = 29.9 > F05 = 2.06), whereas the effects of the year factor (F = 0.82) and of the interaction of the factors (F = 0.61) were not significant. Thus, the pH of peach fruit is determined mainly by cultivar characteristics and depends little on the conditions of the year, which confirms that this trait can serve as a reliable criterion for breeding and for processing. The accuracy of the experiment was Sx = 1.3 %, indicating a high reliability of the results.

Table 1.

Active acidity (pH) of the fruits of peach cultivars, 2022–2024

No.	Cultivar	pH, M ± m	Deviation from the control, ±	Acidity group
1	Champion	4.03 ± 0.02	0.00	medium
2	Elberta (control)	4.03 ± 0.04	—	medium
3	Extreme 514	3.78 ± 0.03	–0.26	acidic
4	Vostok	3.83 ± 0.03	–0.20	acidic
5	Lola	3.69 ± 0.04	–0.34	acidic
6	Super lola	4.08 ± 0.02	+0.05	low-acid
7	Oq luchchak	3.94 ± 0.03	–0.10	medium
8	Big Top	4.11 ± 0.03	+0.07	low-acid
9	Caldesi 2000	4.17 ± 0.01	+0.14	low-acid
	Mean	3.96	—	—
	V, %	4.1	—	—
	Sx, %	1.3	—	—
	LSD05	0.08	—	—

A statistically significant decrease relative to the control, that is, a difference exceeding LSD05 = 0.08, was recorded in Lola (–0.34), Extreme 514 (–0.26), Vostok (–0.20) and Oq luchchak (–0.10); a low pH indicates a high content of organic acids, primarily malic acid, in the fruit flesh [7]. In Caldesi 2000, by contrast, the pH was significantly higher than in the control (+0.14). In Champion (0.00), Super lola (+0.05) and Big Top (+0.07) the differences were within LSD05 and therefore not significant.

The range obtained is consistent with international data: in cultivars studied in the Mediterranean basin the pH of peach ranged from 3.50 to 4.40, and in white-fleshed cultivars it was usually below 4.0 [6]; in our experiment the white-fleshed cultivars Oq luchchak (3.94) and Lola (3.69) likewise had a pH below 4.0. The basis of the differences among cultivars has been explained at the molecular level: in low-acid cultivars the expression of the ALMT9 gene, which transports malate into the vacuole, is reduced, and the degradation of citric acid is accelerated [7].

Nitrate content of the fruit. The content of nitrate ions varied among cultivars from 37.8 to 40.7 mg/kg, with a mean value of 39.1 mg/kg (Table 2). As in the case of pH, the effect of the cultivar factor was significant for this indicator (F = 5.68 > F05 = 2.06), whereas the effects of the year factor (F = 0.11) and of the interaction of the factors (F = 0.99) were not significant. The mean nitrate content by year varied only from 39.1 mg/kg (2022) to 39.2 mg/kg (2023), that is, it remained practically unchanged over the three years. The accuracy of the experiment was Sx = 2.0 %.

Table 2.

Nitrate content of the fruits of peach cultivars, 2022–2024

No.	Cultivar	Nitrate, mg/kg, M ± m	Deviation from the control, ±	Share of MPL, %	Status
1	Champion	38.5 ± 0.6	+0.7	64.2	within the limit
2	Elberta (control)	37.8 ± 0.4	—	63.1	within the limit
3	Extreme 514	38.4 ± 0.4	+0.6	64.0	within the limit
4	Vostok	39.8 ± 0.5	+2.0	66.4	within the limit
5	Lola	37.8 ± 0.5	–0.1	62.9	within the limit
6	Super lola	39.2 ± 0.3	+1.3	65.3	within the limit
7	Oq luchchak	40.3 ± 0.3	+2.5	67.2	within the limit
8	Big Top	39.8 ± 0.4	+2.0	66.4	within the limit
9	Caldesi 2000	40.7 ± 0.4	+2.8	67.8	within the limit
	Mean	39.1	—	65.2	—
	V, %	2.8	—	—	—
	Sx, %	2.0	—	—	—
	LSD05	1.3	—	—	—

Note: MPL is the maximum permissible level of nitrate for stone fruits, 60 mg/kg.

The lowest nitrate content was recorded in the control cultivar Elberta and in Lola (37.8 mg/kg). Values significantly higher than the control, that is, exceeding LSD05 = 1.3 mg/kg, were found in Caldesi 2000 (+2.8), Oq luchchak (+2.5), Vostok and Big Top (+2.0) and Super lola (+1.3), whereas the differences in Champion (+0.7) and Extreme 514 (+0.6) were not significant. In all cultivars the nitrate content was below the MPL; the results, however, require an objective interpretation: the mean values amounted to between 62.9 % and 67.8 % of the MPL, and the highest value in an individual sample reached 43 mg/kg, or 71.7 % of the MPL. The safety margin is therefore 1.5–1.6-fold, and if the rate of nitrogen fertilization were increased or the irrigation regime disturbed, the nitrate content in Caldesi 2000, Oq luchchak and Big Top could approach the MPL; monitoring of individual consignments of these cultivars destined for export should therefore be intensified [10].

A comparison with world data gives a favourable picture: the mean nitrate content of fruits worldwide is 44.02 mg/kg [2], whereas in our experiment the mean value was 39.1 mg/kg, that is, 11.1 % lower than the world average. This shows that peach fruits grown under the conditions of the Fergana region comply with international requirements with respect to nitrate accumulation and that nitrogen fertilizers are applied at reasonable rates in local orchards.

Relationship between pH and nitrate content

A comparison of the data of the two tables revealed an interesting tendency: cultivars with a higher pH, that is, low-acid cultivars, also had a higher nitrate content. Correlation analysis of all 108 observations confirmed this tendency ($r = 0.208$; $p = 0.031$); the relationship, however, is very weak: the coefficient of determination was $R^2 = 0.04$, which means that only 4 % of the variability in nitrate content is associated with pH. At the level of cultivar means the correlation was stronger ($r = 0.481$), but owing to the small number of observations ($n = 9$) it did not reach the threshold of statistical significance ($p = 0.19$). Accordingly, the relationship observed should be regarded not as a regularity of practical importance but as a tendency that requires verification on a larger number of cultivars.

A possible reason for this tendency is a well-known physiological mechanism: the reduction of nitrate with the participation of nitrate reductase is accompanied by the formation of hydroxyl ions (OH^-), and this alkalinity is neutralized through the synthesis of malic acid (the «biochemical pH-stat»). It may therefore be assumed that in low-pH cultivars, in which acid metabolism is more active, nitrate assimilation proceeds more intensively and less residual nitrate accumulates in the fruit. Direct measurement of nitrate reductase activity is required to confirm this explanation. From a practical point of view the tendency observed is important: at a time when the creation of low-acid, sweet-tasting cultivars is becoming a priority direction in breeding [8], it is advisable to evaluate food safety indicators as well when such cultivars are tested.

Risk assessment for nitrate

Compliance with the MPL is a necessary but not a sufficient condition. The calculations showed that when an adult consumer (BW = 60 kg) eats 0.2 kg of peaches per day, the daily intake of nitrate amounts to 0.126–0.136 mg/kg body weight, which is only 3.4–3.7 % of the acceptable daily intake established by EFSA [1]. Even when the daily consumption rises to 0.3 kg and the cultivar with the highest nitrate content is consumed, this share does not exceed 5.5 %. For children, in the least favourable case (BW = 27 kg, IR = 0.1 kg), the value amounted to 4.1 % of the ADI. In all cases the hazard quotient was HQ = 0.034–0.055, that is, 18–29 times below unity, which means that consumption of the fruits of the cultivars studied poses no risk to health with respect to nitrate. This is consistent with the literature: the main part of the dietary nitrate intake comes not from fruits but from vegetables [2; 4].

Technological significance of the result

In all 108 samples the pH was below the microbiological safety threshold of 4.6 and below the value of 4.5 used in processing practice (the highest individual value was 4.25). This makes it possible to classify peach fruits as high-acid foods and to apply pasteurization regimes at 90–100 °C

during canning instead of high-temperature sterilization [9], which reduces energy consumption and better preserves product quality. Caldesi 2000 is the closest to the threshold (mean 4.17), and it is therefore recommended that the pH be monitored in consignments prepared from this cultivar and, where necessary, adjusted with citric acid. On the whole, when the two indicators are analysed together the cultivars may be divided into two groups: cultivars with a low pH and a low nitrate content (Lola, Extreme 514, Elberta) are the most suitable for processing and export, whereas cultivars with a higher pH and a relatively higher nitrate content (Caldesi 2000, Big Top, Super lola, Oq luchchak) are preferable for fresh consumption but require stricter monitoring.

Conclusion

1. In the nine peach cultivars grown in the Uzbekistan district of the Fergana region, the active acidity of the fruit flesh ranged from 3.69 (Lola) to 4.17 (Caldesi 2000), averaging 3.96 (LSD05 = 0.08; Sx = 1.3 %). A significantly lower pH than in the control was recorded in Lola, Extreme 514, Vostok and Oq luchchak.

2. The nitrate content ranged from 37.8 (Elberta, Lola) to 40.7 mg/kg (Caldesi 2000), averaging 39.1 mg/kg (LSD05 = 1.3 mg/kg; Sx = 2.0 %), and in all cultivars it was below the MPL of 60 mg/kg, amounting to 62.9–67.8 % of it. The mean value is 11.1 % lower than the figure reported for fruits worldwide (44.02 mg/kg).

3. The analysis of variance showed a significant effect of the cultivar factor for both indicators ($F = 29.9$ for pH and $F = 5.68$ for nitrate), whereas the effects of the year factor and of the interaction of the factors were not significant. The cultivar-specific differences were therefore stable over the three years and can be regarded as reliable cultivar traits.

4. A very weak positive correlation was observed between pH and nitrate content ($r = 0.208$; $n = 108$; $p = 0.031$; $R^2 = 0.04$): low-acid cultivars tend to accumulate more nitrate, but this relationship is only a tendency and requires verification on a larger number of cultivars.

5. According to the risk assessment, the daily intake of nitrate amounted to 3.4–3.7 % of the ADI for adult consumers and to 4.1 % for children ($HQ < 1$). Since the pH was below 4.5 in all samples, pasteurization regimes may be applied when the fruits are processed. Lola, Extreme 514 and Elberta are recommended for processing and export, while monitoring of pH and nitrate in individual consignments is necessary for Caldesi 2000.

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