commodities

Article

Evaluation of the Quality of Raspberries (*Rubus idaeus* L.) Grown in Balanced Fertilization Conditions

Barbara Sawicka [1,*], Piotr Barbaś [2], Dominika Skiba [1], Barbara Krochmal-Marczak [3] and Piotr Pszczółkowski [4]

[1] Department of Plant Production Technology and Commodity Science, University of Life Sciences in Lublin, Akademicka 15, 20-950 Lublin, Poland; dominika.skiba@up.lublin.pl
[2] Department of Potato Agronomy, Plant Breeding and Acclimatization Institute—National Research Institute, Branch of Jadwisin, Jadwisin, 05-140 Serock, Poland; p.barbas@ihar.edu.pl
[3] Department of Food Production and Safety, Carpathian State College in Krosno, 38-400 Krosno, Poland; barbara.marczak@kpu.krosno.pl
[4] Experimental Station for Cultivar Assessment of Central Crop Research Centre, Uhnin, 21-211 Dębowa Kłoda, Poland; p.pszczolkowski.inspektor@coboru.gov.pl
* Correspondence: barbara.sawicka@up.lublin.pl; Tel.: +48-814456787

Abstract: (Background) Raspberry (*R. idaeus* L.) is very popular with consumers around the world for its intense flavor, attractive appearance, and health benefits. In recent years, interest in healthy eating and natural products has increased, and raspberry fits perfectly into these trends, which translates into its greater importance on the consumer market. (Aim) The aim of this study was the commodity evaluation of raspberry fruits bearing fruit on 2-year-old shoots, cultivated under conditions of varied nitrogen fertilization against the background of constant phosphorus-potassium fertilization. (Methodology) The first-order factors were cultivars ('Laszka' and 'Glen Ample'), and the second-order factor was nitrogen fertilization (0, 50, 100, and 150 kg N ha^{-1}), against the background of constant phosphorus-potassium fertilization (100 kg P_2O_5 and 120 kg K_2O ha^{-1}). The experiment was set up in a dependent split-plot design with three repetitions. (Results) The importance of raspberry on the consumer market was shaped by taste and quality of fruit, health benefits, naturalness and freshness, universality of use, availability, and nutritional trends. (Conclusions) The tested cultivars were characterized by similar production and quality capabilities. Fertilization of the tested cultivars with a dose of 135 kg N·ha^{-1} turned out to be justified in terms of yield. Increasing nitrogen doses resulted in a significant increase in fresh fruit yield and fruit weight. Different doses of nitrogen increased fruit resistance to mechanical damage, firmness, and quality indices.

Keywords: raspberry; quality; commodity assessment; cultivation conditions; nutrient management; sensory evaluation; post-harvest handling; marketability

check for updates

Citation: Sawicka, B.; Barbaś, P.; Skiba, D.; Krochmal-Marczak, B.; Pszczółkowski, P. Evaluation of the Quality of Raspberries (*Rubus idaeus* L.) Grown in Balanced Fertilization Conditions. *Commodities* **2023**, *2*, 220–245. https://doi.org/10.3390/commodities2030014

Academic Editor: Jungho Baek

Received: 19 May 2023
Revised: 16 June 2023
Accepted: 27 June 2023
Published: 11 July 2023

1. Introduction

The raspberry (*R. idaeus* L.) belongs to the rose family *Rosaceae* [1]. This botanical family includes most cultivated trees (e.g., pears, apples, plums, pears, and cherries), fruit bushes (e.g., raspberries and blackberries—Rubus), ornamental shrubs (e.g., rose—Rosa), and perennials (e.g., *Fragaria*) [2–5]. Its natural origins can be found in Europe, North Asia, and North America. In Europe, the raspberry is widespread, especially in the temperate zone. This species has long been cultivated in many European countries, such as Poland, Germany, France, Great Britain, Russia, and Scandinavia. In addition to Europe, the raspberry also occurs naturally in North Asia, in countries such as Russia, Kazakhstan, Mongolia, China, Japan, and Korea. Raspberries are also grown in these regions. In North America, raspberries grow wild. This species is endemic to the continent, with natural ranges from Alaska and Canada to mountainous areas in the United States, including Colorado, Washington, Oregon, and Montana. Thanks to the development of genetics and breeding, the raspberry is now cultivated all over the world in various regions that provide appropriate climatic and soil conditions for this species. The raspberry is very popular among consumers due to its intense taste, attractive appearance, and health benefits [5,6]. There are several factors that influence the importance of the raspberry in the consumer market. These are

– Taste and quality: Raspberries have a distinct, sweet, and sour taste. The degree of ripeness, the cultivar, and the content of simple sugars, organic acids, and volatile substances determine the taste and aroma of the fruit. Fruit should also be fresh, juicy, and of good quality to meet consumer expectations [7–12].
– Health benefits: Raspberry fruit is rich in vitamins, minerals, antioxidants, and fiber, which attracts consumers looking for healthy food. They are also low in calories and can be part of a healthy diet [13–19].
– Naturalness and freshness: Consumers want natural and fresh products, especially when it comes to fruit. Raspberry fruit is often perceived as a natural, seasonal fruit that can be eaten in its original form.
– Versatility of use: Raspberry fruit can be eaten in many different ways—as an independent fruit, an addition to desserts, or an ingredient in cocktails, jellies, jams, and casseroles. This versatility attracts diverse groups of consumers.
– Availability: Raspberries are available on the market most of the year, both in the form of fresh fruit and processed products. This makes them more accessible to consumers [8,10].
– Food trends: In recent years, interest in healthy eating and natural products has increased. The true raspberry fits perfectly into these trends, which translates into their increasing importance on the consumer market [7,8,11].

The quality of raspberry fruits and their importance on the consumer market also depend on factors such as region of cultivation, production methods, local availability, and price competitiveness [4,7,10–12].

The biological value of the raspberry depends to a large extent on the concentration of antioxidants, which include, among others, ascorbic acid and anthocyanins [4,11,12,14]. Raspberry fruit also contains vitamin C, as well as vitamins from the groups B, PP, A, E, and K, and minerals such as potassium, calcium, magnesium, iron, and, in a smaller amount, manganese, copper, and zinc [2,8,9,11]. The presence of these ingredients affects the health-promoting properties of the raspberry. Polyphenols have antioxidant, anti-inflammatory, and antimicrobial effects [13]. They inhibit the formation of free radicals, which adversely oxidize many compounds and damage cell membranes, proteins, lipids, enzymes, and genetic material [11,14–19]. Consumption of products containing these compounds has a beneficial effect on the eyesight and the cardiovascular system [16,20,21]. The fruits of *R. idaeus* L. also contain carotenoid compounds that act as natural plant pigments, including β-carotene, zeaxanthin, and lutein [22,23]. Zeaxanthin and lutein give color to yellow-fruited cultivars that do not contain anthocyanins. Raspberry is a rich source of phenolic acids, which include ellagic and salicylic acids [17,18,21,23]. Ellagic acid has anticancer and antioxidant properties, while salicylic acid has analgesic, antipyretic, and anti-inflammatory properties [13,14,16,19,24].

However, raspberry fruits are very susceptible to mechanical damage, water loss, and mold development during transport and storage. For these reasons, the viability of the raspberry after harvest is limited to a few days, usually 3 to 5 days, and only a small percentage of these fruits can be eaten fresh [10,17]. To prevent these defects, it is recommended to store the fruit at a temperature close to 0 °C. However, storing fruit at a low temperature is insufficient to extend the shelf life of raspberry fruit to 14 days, and more and more often, storage is carried out in a controlled atmosphere [25–29]. Maintaining the concentration of CO_2 at a level of 5–20% and O_2 at a level of 3–10% ensures an increase in the durability of stored *R. idaeus* fruits. Reducing the O_2 concentration below 3% may, however, cause deterioration of the taste, while exceeding the CO_2 level above 30% increases the softening of the fruit and causes brown discoloration of the skin [21,28,29].

The yield and quality of *R. idaeus* fruits are also determined by cultivars, appropriate cultivation management, including fertilization, especially with nitrogen, and care treatments [30,31].

The genetic features of the cultivars studied may have a significant impact on both the yield and the qualitative characteristics of a given species. Genetic characteristics of *R. idaeus* L., such as growth potential, ability to form fruit, ripening date, or plant structure, may affect the yield. Cultivars with greater growth potential, more fruit per plant, or a more optimal ripening date may produce higher yields. Important consumption features of raspberries are the taste and aroma of the fruit. For example, some raspberry cultivars may have an intense, sweet flavor, while others may be more acidic. Aromatic properties may also vary depending on the genetic characteristics of the cultivar. Similarly, genetic characteristics determine the size and shape of the fruit. Larger-fruited cultivars may deliver higher yields, while more regular-shaped cultivars may be favored by the market. The genetic characteristics of cultivars can affect fruit consistency and post-harvest shelf life. Appropriate genetic features can ensure greater durability, better protection against mechanical damage, and rapid fruit spoilage. Genetic diversity in plant breeding allows the selection and development of cultivars with desirable characteristics, such as yield, taste, shelf life, and others [31].

The use of nitrogen fertilizers is very important due to the fact that nitrogen is a component of amino acids that form structural proteins and enzymes important for metabolism, nucleic acids, and chlorophyll [17].

Consumers purchasing raspberry fruit pay special attention to quality features such as color, size, and shape. The color affects the appearance and attractiveness, as well as freshness and taste. Quality standards for fresh fruit intended for consumption in international trade are defined by the European standard UN/ECE FFV-32, which provides for three quality classes: Extra, I, and II. In each of them, healthy, clean fruit, without foreign smells, with a fresh appearance, free from pests and damage, and not damp, is allowed to be marketed. The size of the fruits of cultivars depends on determining the largest diameter, which for individual fractions is Extra—15 mm, I—12 mm [32]. In the case of class II raspberries, the size is not specified [32]. Quality classes differ in the share of fruit with defects and the degree of tolerance of these defects, e.g., separating raspberry fruits after a period of drought and repeated rainfall. Each batch of fruit must be uniform and properly labeled [33]. Therefore, the aim of this study was to carry out a commodity evaluation of the fruits of two raspberry cultivars bearing fruit on 2-year-old shoots, cultivated under the conditions of differentiated nitrogen fertilization against the background of constant phosphorus-potassium fertilization. The alternative hypothesis assumes that there is a statistically significant difference in the quality of raspberries (*R. idaeus* L.) grown under balanced fertilization conditions in relation to the null hypothesis that there is no significant difference in the quality of raspberries grown under balanced fertilization conditions.

2. Results

2.1. Fruit Yield

The average fruit yield of raspberries was 8.44 t·ha^{-1}. The cultivar 'Glen Ample' turned out to be more prolific and yielded 6.8% more than the cultivar 'Laszka'. A successive, significant increase in fruit yield was observed under the influence of successively increasing doses of nitrogen. The highest yield was obtained in the object with 135 kg N ha^{-1}. Harvest dates did not differentiate fruit yield (Table 1).

The interaction of experimental factors did not have a significant effect on the fruit yield (Table 1).

2.2. Thousands of Fruits

The average weight of 1000 raspberry fruits was 7.75 kg (Table 2). All factors in the experiment had a significant impact on the examined feature. The weight of 1000 raspberry fruits was higher for the 'Laszka' cultivar by 20.8% compared with the 'Glen Ample' cultivar. Differentiated nitrogen fertilization had a significant effect on the weight of 1000 fruits. A significant increase in the value of this feature was observed at fertilization of 135 kg N·ha^{-1}. The highest weight of 1000 raspberry fruits was recorded on the first date of harvest for both cultivars. As the harvest dates were delayed, a successive decrease in the value of this feature was observed.

Table 1. Influence of cultivar, fertilization, and harvest date on raspberry fruit yield (t ha^{-1}).

Cultivars	Fertilization	Harvest Dates *			Mean
		1	**2**	**3**	
'Laszka'	0	4.31 a	4.35 a	4.12 a	4.26 a
	45	6.35 a	6.03 a	6.28 a	6.22 a
	90	9.26 a	9.07 a	9.31 a	9.21 a
	135	12.97 a	12.90 a	12.81 a	12.89 a
	Mean	8.22 a	8.09 a	8.13 a	8.15 b
'Glen Ample'	0	4.58 a	4.62 a	4.52 a	4.57 a
	45	6.84 a	6.68 a	6.74 a	6.75 a
	90	10.59 a	10.63 a	10.54 a	10.59 a
	135	13.00 a	12.97 a	13.14 a	13.04 a
	Mean	8.75 a	8.73 a	8.74 a	8.74 a
Mean	0	4.45 a	4.49 a	4.32 a	4.42 d
	45	6.60 a	6.36 a	6.51 a	6.49 c
	90	9.93 a	9.85 a	9.93 a	9.90 b
	135	12.99 a	12.94 a	12.98 a	12.97 a
	Mean	8.49 a	8.41 a	8.43 a	8.44
LSD$p_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a, b, c, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

Table 2. Influence of cultivar, fertilization, and harvest dates on 1000 fruit weight [kg].

Cultivars	Fertilization	Harvest Dates *			Mean
		1	**2**	**3**	
'Laszka'	0	8.34 a	7.81 a	7.18 a	7.78 b
	45	9.85 a	8.55 a	7.41 a	8.60 a
	90	9.77 a	8.90 a	7.90 a	8.86 a
	135	10.29 a	9.70 a	8.11 a	9.37 a
	Mean	9.56 a	8.74 a	7.65 a	8.65 a
'Glen Ample'	0	6.84 a	6.20 a	6.16 a	6.40 a
	45	7.01 a	6.64 a	6.23 a	6.63 a
	90	7.44 a	6.94 a	6.58 a	6.99 a
	135	7.98 a	7.20 a	6.94 a	7.37 a
	Mean	7.32 b	6.75 b	6.48 a	6.85 b
Average for fertilization	0	7.59 a	7.01 b	6.67 a	7.09 b
	45	8.43 a	7.60 a	6.82 a	7.62 a
	90	8.61 a	7.92 a	7.24 a	7.92 a
	135	9.14 a	8.45 a	7.53 a	8.37 a
	Mean	8.44 a	7.74 b	7.06 c	7.75
LSD$p_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a, b, c, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

2.3. Juice Yield

The average juice yield from 1 kg of fresh raspberry fruit was 0.673 dm^3 (Table 3). Only cultivars had a significant impact on the examined trait. The 'Glen Ample' cultivar showed better juice yield and was higher than the 'Laszka' cultivar by 7.7%. A higher juice yield was obtained on the third date of harvest than on the other dates, but it was not the significantly highest value (Table 3).

Table 3. Influence of cultivar, fertilization, and harvest dates on juice yield from 1 kg of fresh fruit [dm^3].

Cultivars	Fertilization	Harvest Dates *			Mean
		1	2	3	
'Laszka'	0	0.630 a	0.646 a	0.636 a	0.637 a
	45	0.633 a	0.651 a	0.646 a	0.643 a
	90	0.646 a	0.651 a	0.663 a	0.653 a
	135	0.650 a	0.646 a	0.650 a	0.648 a
	Mean	0.640 a	0.648 a	0.649 a	0.646 b
'Glen Ample'	0	0.680 a	0.687 a	0.700 a	0.689 a
	45	0.693 a	0.710 a	0.703 a	0.702 a
	90	0.690 a	0.706 a	0.706 a	0.701 a
	135	0.700 a	0.703 a	0.720 a	0.707 a
	Mean	0.690 a	0.701 a	0.707 a	0.700 a
Average for fertilization	0	0.655 a	0.667 a	0.668 a	0.663 a
	45	0.663 a	0.680 a	0.675 a	0.673 a
	90	0.668 a	0.679 a	0.685 a	0.677 a
	135	0.675 a	0.674 a	0.685 a	0.678 a
	Mean	0.665 a	0.675 a	0.678 a	0.673
$LSDp_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a, b, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

2.4. Fruit Dry Matter Content

The average dry matter content of raspberry fruit was 18.13% (Table 4). All factors in the experiment had a significant impact on the examined feature. The 'Laszka' cultivar was characterized by a higher content of dry matter, which was a difference of 5.27% in comparison with the 'Glen Ample' cultivar. Increasing the nitrogen dose resulted in a successive decrease in the dry matter content. The highest dry matter content for both cultivars was observed on the first date and the lowest on the third date of harvest (Table 4).

2.5. Fruit Quality

On the first day of harvest, the experimental factors did not have a significant impact on the organoleptic evaluation. The highest score in this period was given to the appearance and consistency of the fruit. The shape and color of the fruit were at the same level, and the lowest score was given to the taste of the fruit (Table 5).

In the second harvest, only the taste and color of the fruit depended significantly on the experimental factors (Table 6). Cultivars were the factor that differentiated these features. The 'Glen Ample' cultivar had a better taste, while the fruit of the 'Laszka' cultivar had a brighter color. The consistency of the fruit was at the highest level among the assessed features. Nitrogen fertilization did not significantly affect any of the assessed traits. Only a tendency to improve the aroma and consistency of fruit was observed under the influence of fertilization with higher doses of nitrogen.

Table 4. Influence of cultivar, fertilization, and harvest dates on fruit dry matter content [%].

Cultivars	Fertilization	Harvest Dates *			Mean
		1	2	3	
'Laszka'	0	25.00 a	23.67 a	20.33 a	23.00 a
	45	22.67 a	23.33 a	18.67 a	21.56 a
	90	21.90 a	21.33 a	18.00 a	20.41 a
	135	20.67 a	19.00 a	14.67 a	18.11 b
	Mean	22.58 a	21.83 a	17.92 b	20.77 a
'Glen Ample'	0	18.00 a	17.33 a	17.33 a	17.56 a
	45	16.33 a	15.00 a	16.33 a	15.89 a
	90	16.33 a	13.33 a	15.33 a	15.00 a
	135	15.00 a	12.00 a	13.67 a	13.56 b
	Mean	16.42 a	14.42 a	15.67 a	15.50 b
Average for fertilization	0	21.50 a	20.50 a	18.83 a	20.28 a
	45	19.50 a	19.17 a	17.50 a	18.72 a
	90	19.12 a	17.33 a	16.67 a	17.71 b
	135	17.83 a	15.50 a	14.17 a	15.83 c
	Mean	19.49 a	18.13 a	16.79 b	18.13
$LSDp_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a, b, c, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

Table 5. Influence of cultivar and fertilization on the organoleptic evaluation of fruit at the first harvest date [in 5° scale].

Cultivars	Fertilization	Organoleptic Assessment					
		Taste	Smell	Color	Shape	Appearance	Consistency
'Laszka'	0	4.3 a	4.7 a	4.8 a	4.9 a	4.8 a	4.8 a
	45	4.4 a	4.3 a	4.5 a	4.6 a	4.7 a	4.8 a
	90	4.7 a	4.5 a	4.8 a	4.6 a	4.8 a	4.8 a
	135	4.2 a	4.8 a	4.7 a	4.8 a	4.7 a	5.0 a
	Mean	4.4 a	4.6 a	4.7 a	4.7	4.8 a	4.9 a
'Glen Ample'	0	4.5 a	4.6 a	4.5 a	4.9 a	4.9 a	4.9 a
	45	4.5 a	4.7 a	4.7 a	4.6 a	4.8 a	4.9 a
	90	4.5 a	4.6 a	4.8 a	4.7 a	4.7 a	4.8 a
	135	4.5 a	4.4 a	4.5 a	4.7 a	4.7 a	4.6 a
	Mean	4.5 a	4.6 a	4.6 a	4.7 a	4.8 a	4.8 a
Average for fertilization	0	4.4 a	4.7 a	4.7 a	4.9 a	4.9 a	4.9 a
	45	4.5 a	4.5 a	4.6 a	4.6 a	4.8 a	4.9 a
	90	4.6 a	4.6 a	4.8 a	4.7 a	4.8 a	4.8 a
	135	4.4 a	4.6 a	4.6 a	4.8 a	4.7 a	4.8 a
	Mean	4.5	4.6	4.7	4.7	4.8	4.8
$LSDp_{0.05}$							

Letter indicators (a, b, c, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

In the third term of harvest, the factors of the experiment did not have a significant impact on the organoleptic evaluation of raspberry fruit (Table 7). The highest organoleptic score was obtained for fruit consistency (4.8° on a scale of 5°), while aroma and taste received the lowest scores, regardless of the cultivar and the level of nitrogen fertilization.

Table 6. Influence of cultivar and fertilization on organoleptic evaluation of fruit in the 2nd term of harvest [scale 5°].

Cultivars	Fertilization	Organoleptic Assessment					
		Taste	Smell	Color	Shape	Appearance	Consistency
'Laszka'	0	4.3 a	4.5 a	4.8 a	4.6 a	4.7 a	4.6 a
	45	4.2 a	4.5 a	4.8 a	5.0 a	4.8 a	4.8 a
	90	4.5 a	4.6 a	4.8 a	4.6 a	4.6 a	4.9 a
	135	4.2 a	4.8 a	4.7 a	4.8 a	4.7 a	5.0 a
	Mean	4.3 b	4.6 a	4.8 a	4.8 a	4.7 a	4.8 a
'Glen Ample'	0	4.4 a	4.6 a	4.5 a	4.9 a	4.9 a	4.9 a
	45	4.6 a	4.7 a	4.6 a	4.6 a	4.4 a	4.9 a
	90	4.7 a	4.5 a	4.6 a	4.6 a	4.7 a	4.8 a
	135	4.6 a	4.5 a	4.4 a	4.7 a	4.6 a	4.6 a
	Mean	4.6 a	4.6 a	4.5 b	4.7 a	4.7 a	4.8 a
Average for fertilization	0	4.4 a	4.6 a	4.7 a	4.8 a	4.8 a	4.8 a
	45	4.4 a	4.6 a	4.7 a	4.8 a	4.6 a	4.9 a
	90	4.6 a	4.6 a	4.7 a	4.6 a	4.7 a	4.9 a
	135	4.4 a	4.7 a	4.6 a	4.8 a	4.7 a	4.8 a
	Mean	4.4	4.6	4.7	4.7	4.7	4.8
$LSDp_{0.05}$							

Letter indicators (a, b, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

Table 7. Influence of cultivar and fertilization on organoleptic evaluation of fruit in the 3rd term of harvest [scale 5°].

Cultivars	Fertilization	Organoleptic Assessment					
		Taste	Smell	Color	Shape	Appearance	Consistency
'Laszka'	0	4.3 a	4.7 a	4.6 a	4.9 a	4.7 a	4.8 a
	45	4.2 a	4.3 a	4.6 a	4.7 a	4.7 a	4.8 a
	90	4.6 a	4.4 a	4.9 a	4.6 a	4.9 a	4.9 a
	135	4.2 a	4.7 a	4.6 a	4.7 a	4.5 a	4.9 a
	Mean	4.3 a	4.5 a	4.7 a	4.7 a	4.7 a	4.9 a
'Glen Ample'	0	4.5 a	4.6 a	4.5 a	4.8 a	4.7 a	4.8 a
	45	4.3 a	4.6 a	4.6 a	4.6 a	4.6 a	4.8 a
	90	4.3 a	4.6 a	4.8 a	4.7 a	4.7 a	4.8 a
	135	4.4 a	4.3 a	4.6 a	4.7 a	4.7 a	4.9 a
	Mean	4.4 a	4.5 a	4.6 a	4.7 a	4.7 a	4.8 a
Average for fertilization	0	4.4 a	4.7 a	4.6 a	4.9 a	4.7 a	4.8 a
	45	4.3 a	4.5 a	4.6 a	4.7 a	4.7 a	4.8 a
	90	4.5 a	4.5 a	4.9 a	4.7 a	4.8 a	4.9 a
	135	4.3 a	4.5 a	4.6 a	4.7 a	4.6 a	4.9 a
	Mean	4.4	4.5	4.7	4.7	4.7	4.8
$LSDp_{0.05}$							

Letter indicators (a) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

2.6. Transport Resistance

The resistance of raspberry fruits to transport was assessed on average at 4.6° on a 5° scale (Table 8). Varietal properties and harvest dates significantly differentiate the value of this feature. The 'Laszka' cultivar was characterized by a higher resistance to transport than the 'Glen Ample' cultivar. On the first date of harvest, the fruits were the most resistant to transport, while those harvested on the second and third dates were characterized by a reduced level of strength. However, the fruits differed significantly in terms of resistance to transport only on the first and third dates of harvest. The reaction of the tested cultivars to nitrogen fertilization was similar.

Table 8. Influence of cultivar, fertilization, and harvest dates on fruit resistance during transport [scale 5°].

Cultivars	Fertilization	Harvest Dates *			Mean
		1	2	3	
'Laszka'	0	4.7 a	5.0 a	4.7 a	4.8 a
	45	4.7 a	4.7 a	4.7 a	4.7 a
	90	5.0 a	4.7 a	5.0 a	4.9 a
	135	5.0 a	4.7 a	5.0 a	4.9 a
	Mean	4.8 a	4.8 a	4.8 a	4.8 a
'Glen Ample'	0	4.3 a	4.0 a	3.7 a	4.0 a
	45	4.7 a	4.3 a	4.3 a	4.4 a
	90	5.0 a	4.7 a	4.7 a	4.8 a
	135	4.7 a	4.7 a	4.3 a	4.6 a
	Mean	4.7 a	4.4 a	4.3 a	4.4 b
Average for fertilization	0	4.5 a	4.5 a	4.2 a	4.4 a
	45	4.7 a	4.5 a	4.5 a	4.6 a
	90	5.0 a	4.7 a	4.8 a	4.8 a
	135	4.8 a	4.7 a	4.7 a	4.7 a
	Mean	4.8 a	4.6 a	4.5 b	4.6
LSD$p_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a, b, c, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

2.7. Rheological Features

The rheological properties of the raspberry, such as maximum load, work, and final load, refer to their mechanical and textural properties. Maximum load is a measure of the maximum force a raspberry fruit can withstand before it becomes deformed or crushed. It is measured in grams (g) and reflects the strength of the structure of the raspberry fruit. Higher values of the maximum load indicate greater strength in raspberry fruit.

Work refers to the energy needed to cause the deformation of raspberry fruit. It is measured in milli joules (mJ) and is a measure of the flexibility and springiness of raspberry fruit. Higher values of work indicate greater flexibility and the ability of raspberry fruit to absorb energy during deformation.

The final load is the force at which the raspberry fruit reaches its final deformation or destruction. It is measured in grams (g) and reflects the point at which the fruit loses its elasticity and becomes irreversibly deformed. Higher values of the final load indicate greater strength of the raspberry fruit against damage.

The average maximum fruit load was 365.8 g (Table 9). Varietal properties significantly differentiate the value of rheological features. The 'Glen Ample' cultivar showed a higher value of the maximum load compared with the 'Laszka' cultivar by 18%. Nitrogen fertilization had no significant effect on the maximum load. The reaction of the tested cultivars to fertilization turned out to be varied. Cultivar 'Laszka' reacted to high nitrogen fertilization at a rate of 135 kg N ha^{-1} with lower values of the maximum load, which indicates a decrease in the resistance of raspberry fruit to crushing.

Table 9. Influence of cultivar and fertilization on fruit rheological evaluation and rheological features.

Cultivars	Fertilization	Rheological Evaluation		
		Maximum Load [g]	Work [mJ]	Final Load [g]
'Laszka'	0	368.5 a	34.4 a	399.8 a
	45	328.0 a	29.0 a	316.1 a
	90	344.6 a	32.3 a	325.9 a
	135	274.6 b	30.9 a	326.9 a
	Mean	328.9 a	31.7 b	342.2 b
'Glen Ample'	0	368.4 b	34.4 a	366.5 a
	45	429.1 a	42.3 a	425.7 a
	90	363.7 b	38.3 a	362.7 a
	135	449.5 a	40.3 a	404.6 a
	Mean	402.7 a	38.8 a	389.9 a
Average for fertilization	0	368.5 a	34.4 a	383.2 a
	45	378.6 a	35.7 a	370.9 a
	90	354.2 a	35.3 a	344.3 a
	135	362.1 a	35.6 a	365.8 a
	Mean	365.8	35.2	366.0
LSD$p_{0.05}$				

Letter indicators (a, b, etc.) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

On the other hand, the 'Glen Ample' cultivar responded with an increase in crush resistance in objects fertilized with a dose of 135 kg ha^{-1} compared with the control object without nitrogen fertilization (Table 9).

The average value of the work performed was 35.2 mJ. Only the genetic features of the tested cultivars shaped this feature. The 'Glen Ample' cultivar was characterized by a higher work value, which indicates greater flexibility and the ability of raspberry fruit to absorb energy during deformation than in the case of the 'Laszka' cultivar (Table 9).

The final load was 366.0 g and was modified only by the cultivar factor. More work was needed to deform the fruit in the case of the 'Glen Ample' cultivar, which indicates a higher resistance of the fruit to damage than in the case of the 'Laszka' cultivar. Nitrogen fertilization and cultivar x fertilization interactions had no significant effect on the crushing strength of raspberry fruit (Table 9).

2.8. Fruit Storage Life

Raspberry fruits, stored for 24 h at 10 °C, showed a slight loss of fruit mass as a result of respiration and evaporation. Their average weight loss was 1.91% and did not depend significantly on the experimental factors or their interactions (Table 10).

Table 10. Influence of cultivars, fertilization, and harvest date on the weight loss of stored fruits [%].

Cultivars	Fertilization	Harvest Dates *			Mean
		1	2	3	
'Laszka'	0	1.74 a	1.83 a	1.87 a	1.81 a
	45	1.89 a	1.91 a	1.90 a	1.90 a
	90	1.90 a	1.93 a	1.97 a	1.93 a
	135	1.90 a	1.98 a	1.83 a	1.90 a
	Mean	1.86 a	1.91 a	1.89 a	1.89 a

Table 10. *Cont.*

Cultivars	Fertilization	Harvest Dates *			Mean
		1	2	3	
'Glen Ample'	0	1.71 a	1.90 a	1.87 a	1.83 a
	45	1.97 a	2.03 a	1.90 a	1.97 a
	90	1.94 a	2.01 a	1.90 a	1.95 a
	135	2.03 a	1.97 a	1.92 a	1.97 a
	Mean	1.91 a	1.98 a	1.90 a	1.93 a
Average for fertilization	0	1.73 a	1.87 a	1.87 a	1.82 a
	45	1.93 a	1.97 a	1.90 a	1.93 a
	90	1.92 a	1.97 a	1.94 a	1.94 a
	135	1.97 a	1.98 a	1.88 a	1.94 a
	Mean	1.89 a	1.95 a	1.90 a	1.91
LSD$p_{0.05}$					

* 1st harvest date—27.06, 2nd harvest date—09.07, 3rd harvest date—20.07. Letter indicators (a) next to the averages refer to the so-called homogeneous (statistically homogeneous) groups. The occurrence of the same letter indicator next to the means (at least one) means that there were no statistically significant differences at $p_{0.05}$ between them.

3. Material and Methods

The research was based on a field experiment. They were located in the village of Rozbórz Długi (Figure 1), located in the Przemyśl Foothills (Geographical location: 49°55′45″ N, 22°29′18″ E), on brown, slightly acidic soil.

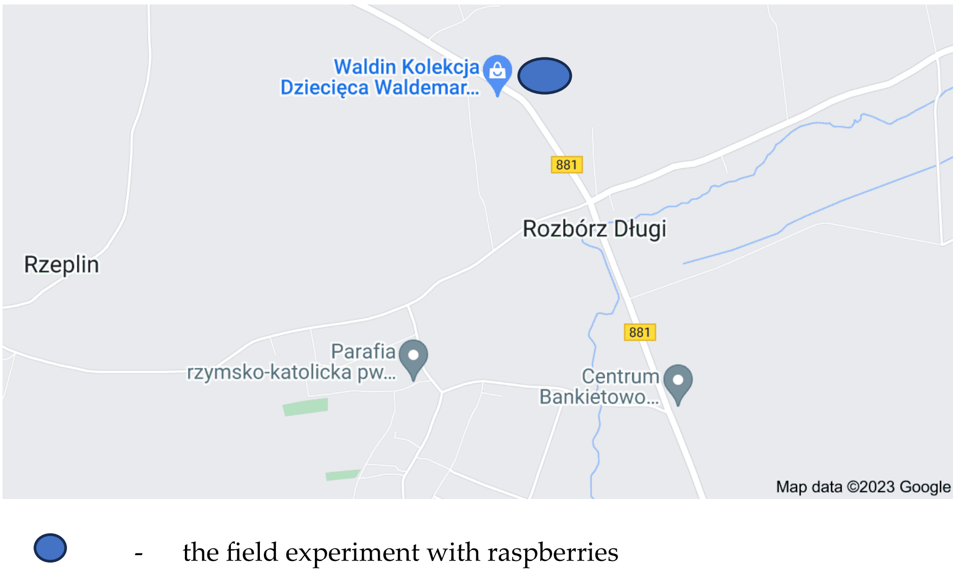

Figure 1. Location of the field experiment with raspberries in Rozbórz Długi, Przemyśl poviat. Source: https://www.google.com/search?q=rozborz+dlugi+mapa+google&sxsrf (accessed on 16 June 2023).

The experiment was performed using the randomized block method in a dependent split-plot design with 3 repetitions. The first-order factors were 2 raspberry cultivars, 'Laszka' and 'Glen Ample', bearing fruit on two-year-old shoots. The second-order factor was differentiated nitrogen fertilization (0, 45, 90, 135 kg N·ha^{-1}), against the background of constant phosphorus-potassium fertilization and full dose of manure (40 t·ha^{-1}). The area of one plot was 4000 m^2.

3.1. Characteristics of Cultivars

'Laszka'—a cultivar bred in the Experimental Department of the Institute of Pomology and Floriculture in Brzezna. It was entered into the National Register of Original Cultivars in 2006 (Figure 2) [34].

Figure 2. 'Laszka' cultivar. Source: P. Barbaś.

The fruits are large and very large, elongated, intensely red in color, and have a slight mossy appearance. It is resistant to frost, dieback of shoots, and fruit rot. The fruits have a long post-harvest shelf life and are less susceptible to damage during transport [33]. Its fertility and fruit size are useful in the production of consumption and dessert fruit. It is a cultivar recommended for controlled cultivation for accelerated harvest due to early ripening and high content of ascorbic acid in the fruit [33,35].

Glen Ample' is a cultivar bred at the Scottish Institute of Crop Production in Dundee, but it can be grown in Poland (Figure 3). A high-yielding cultivar with strong growth and compact, bright red fruits [33,35]. A typical dessert cultivar with an attractive appearance and very good taste [36]. It is characterized by frost resistance and very high resistance to diseases and transport [35].

Figure 3. 'Glen Ample' cultivar. Source: P. Barbaś.

3.2. Agrotechnical Conditions

The forecrop of the raspberry was white mustard. In the autumn of 2018, deep plowing (35 cm) was performed with manure and mineral, phosphorus-potassium fertilizers in the amounts of 150 kg K and 80 kg P, 75 kg Mg, and 150 kg Ca·ha^{-1}. These fertilizers were introduced in the form of polifoska 6 (NPK—6-20-30), potassium salt 60%, and magnesium lime (CaO, MgO—30-15), then a cultivation unit was used.

Raspberry seedlings, qualifying as grade C, were planted at a spacing of 2.5 m, every 0.5 m in a row. The plant density was 10,000 pcs·ha^{-1}. After the acceptance of the seedlings, nitrogen fertilization was applied in the amount of 10 kg N·ha^{-1} in three equal doses, every 20 days, in the form of 34% ammonium nitrate. In addition, in order to provide young seedlings with the necessary microelements, Florovit liquid, multi-component foliar, and soil fertilizer were applied.

In 2019, in the spring, white clover was sown in the rows of raspberries in an amount of 8 kg·ha^{-1} in order to eliminate some weeds and enrich the soil with nitrogen. In the autumn of that year, after examining the abundance of assimilable macronutrients in the soil, the basic mineral fertilization with phosphorus and potassium was established at a dose of 90 kg K·ha^{-1} (in the form of 60% potassium salt in the amount of 150 kg ha^{-1}) and phosphorus in the form of granulated simple superphosphate (20% P) in the amount of 100 kg ha^{-1}.

In 2020, the plantation was divided into blocks, subblocks, and repeats, leaving drive paths. According to the planned scheme of the experiment, mineral fertilization with nitrogen was introduced. Nitrogen doses above 45 kg ha^{-1} were divided into 2 or 3 parts, depending on the size of the dose.

The dose of 90 kg N was applied in 2 parts:

- The first dose (in the amount of 45 kg N ha^{-1}) was applied in early spring at the beginning of vegetation—in the form of 34% ammonium nitrate;
- The second dose—in the amount of 45 kg N ha^{-1} was applied after the flowering of raspberry shoots in the form of 46% urea.
- The dose of nitrogen in the amount of 135 kg N ha^{-1} was divided into 3 parts:
- The first dose (in the amount of 45 kg N ha^{-1}) was applied in early spring at the beginning of vegetation—in the form of 34% ammonium nitrate;
- The second dose—in the amount of 45 kg N ha^{-1} was introduced before the flowering of raspberry shoots in the form of 46% urea;
- The third dose—in the amount of 45 kg N ha^{-1} was applied after flowering of raspberry shoots in the foliar form. An amount of 100 kg of urea was dissolved in 900 dm^3 of water and used for 3 periods, every 7 days.

The adopted methods and divisions of nitrogen doses were aimed at optimizing the fertilization of raspberry plantations, taking into account the various stages of plant development and their demand for nutrients. The appropriate amount of ammonium nitrate or urea is dissolved in the water. The dose of nitrogen was adjusted to the needs of the plants and depended on their age and general condition. The appropriate ratio of nitrogen to water was maintained in accordance with the fertilizer manufacturer's recommendations. The sprayer was prepared and configured to ensure even and thorough spraying of the fertilizer solution on raspberry leaves. Then, foliar spraying with nitrogen was carried out at the appropriate moment of plant development. Foliar fertilization was carried out in the morning or evening to avoid application in full sun. The fertilizer solution was sprayed evenly on raspberry leaves, trying to cover as much of the leaf surface as possible and avoiding too thick a solution that may cause burning of the leaves.

Dosage and frequency of foliar fertilization with nitrogen were adjusted to the needs of plants and their conditions. It should be noted that foliar fertilization was supplemented with basic soil fertilization in accordance with the fertilizer manufacturer's recommendations and the principles of good agricultural practice. Regular monitoring of plant health and adjustment of fertilization were crucial to maintaining a healthy and productive raspberry plantation.

The quality of raspberry fruit was assessed on the basis of the following: weight of 1000 fruits, organoleptic evaluation of fruit; dry matter, juice yield, fruit storage life, transport resistance, and rheological evaluation. The weight of the harvested fruit was determined using a laboratory balance.

3.3. Fruit Picking

It is important to determine the optimal date of fruit harvest, which will reduce losses and obtain good-quality fruit for processing or storage. The fruits of the true raspberry reach harvest maturity when they are fully ripe. Harvest is carried out every 2–3 days as the fruit ripens, but the fruit must not be overripe as it becomes too soft and unsuitable for transport. The fruit harvest on the experimental plantation was preceded by organizational work, securing manual work, and mechanical equipment.

Raspberry fruits were collected in small 0.25 kg packages, which were then placed in collecting containers (Figure 4). After harvesting, the fruits were cooled to +2 °C to +5 °C in the shortest possible time.

Figure 4. Raspberry fruits of the 'Laszka' cultivar in 0.25 kg packages in a collective container. Source: D. Skiba.

3.4. Meteorological Conditions

The course of air temperature and precipitation during the raspberry growing season in 2019/2020 was varied, as illustrated by the results in Table 11.

Precipitation in July 2019 was abundant, reaching 235.4 mm, which was 247.3% of the long-term average. The average air temperature in July was 18.9 °C, with a deviation of 0.2 °C, indicating a slight deviation from the norm. August 2019 experienced low precipitation of 30.7 mm, only 45.0% of the long-term average. The average air temperature in August was 20.4 °C, with a deviation of −2.1 °C. September 2019 had very minimal precipitation of 8.3 mm, representing only 15.2% of the long-term average. October 2019 recorded an average precipitation of 29.9 mm, accounting for 72.0% of the long-term average. November 2019 had extremely low precipitation, with only 0.6 mm, just 1.8% of the long-term average. December 2019 experienced average precipitation of 27.2 mm, equivalent to 95.8% of the long-term average. January 2020 had moderate precipitation of 49.8 mm, reaching 145.2% of the long-term average. February 2020 recorded average precipitation of 25.4 mm, representing 86.1% of the long-term average. Finally, in March 2020, there was again average precipitation of 28.1 mm, accounting for 80.1% of the long-term average (Table 11).

In April 2020, there was low rainfall of 27.6 mm, only 60.1% of the long-term average. The highest precipitation occurred in the third decade, with 18.6 mm. May 2020 experienced an average precipitation of 57.4 mm, representing 86.8% of the long-term average. The highest rainfall was recorded in the second decade, at 33.9 mm. June 2020 had low precipitation of 53.2 mm, accounting for 67.9% of the long-term average. The highest precipitation occurred in the first decade, with 24.0 mm. July 2020 recorded low precipitation of 48.7 mm, only 51.2% of the long-term average. The highest precipitation occurred in the first decade, with 19.3 mm. August 2020 had average precipitation of 57.9 mm, reaching 84.9% of the long-term average. The highest rainfall occurred in the third decade, with 29.3 mm (Table 11).

Table 11. Precipitation, air temperate, and the Sielianinov hydrothermal coefficient in Przemyśl.

Year	Month	Monthly Precipitation (mm)					% of the Norm *	Air Temperature (°C)				Hydrothermal Coefficient of Sielianinov (HTC) ***
		Decade			Sum ****	Multi-Year Average		Average Over the Decade			Month Average **	
		1	2	3				1	2	3		
2019	July	81.2	76.1	78.1	235.4	95.2	247.3	20.2	17.9	18.6	18.9	2.5
	August	12.6	11.3	6.8	30.7	68.2	45.0	23.6	19.5	18.2	20.4	1.5
	September	0.0	0.0	8.3	8.3	54.6	15.2	19.1	16.8	15.2	17.0	0.5
	October	0.0	7.8	22.1	29.9	41.5	72.0	13.2	10.9	9.1	11.1	2.7
	November	0.0	0.6	0.0	0.6	33.2	1.8	7.4	3.2	2.4	4.3	0.1
	December	10.3	10.5	6.4	27.2	28.4	95.8	4.1	1.2	−1.4	1.3	0.0
2020	January	8.0	10.6	31.2	49.8	34.3	145.2	−1.9	−2.9	−3.6	−2.8	0.0
	February	0.0	12.8	12.6	25.4	29.5	86.1	−11.6	−15.1	−10.8	−12.5	0.0
	March	12.7	15.4	0.0	28.1	35.1	80.1	−9.7	−4.2	1.0	−4.3	0.0
	April	9.0	0.0	18.6	27.6	45.9	60.1	0.7	5.4	7.4	4.5	0.0
	May	23.5	33.9	0.0	57.4	66.1	86.8	9.4	14.6	19.1	14.4	4.0
	June	24.0	16.8	12.4	53.2	78.4	67.9	19.1	18.4	21.2	19.6	2.7
	July	19.3	17.4	12.0	48.7	95.2	51.2	22.7	25.1	24.6	24.1	2.0
	August	0.0	28.6	29.3	57.9	68.2	84.9	22.8	21.4	19.5	21.2	2.7
Total		200.6	241.8	237.8	680.2	55.3	81.4	9.9	9.4	10.0	9.8	2.1

Source: Own study based on the meteorological station in Przemyśl in 2019/2020; * in relation to the average in the years 1999–2020 according to the meteorological station in Przemyśl; ** Hydrothermal coefficient of k = (P 10)/∑t, where P—monthly sum of precipitation in mm; ∑t—sum of average daily air temperatures > 0 °C. *** Evaluation of the month according to Sielianinov [37]: <0.5—drought; 0.5–1—drought; 1.1–2—moist; >2—very humid; **** monthly amount of precipitation.

3.5. Soil Conditions

The experiment was set up on brown soil with a slightly acidic reaction and moderate humus content. The content of assimilable phosphorus and potassium in the soil was high; magnesium was medium. The content of micronutrients was moderate, except for the low content of boron (Table 12).

Table 12. Physico-chemical soil analysis.

Parameter *	Unit	2019	2020
pH in KCl	-	5.9	6.2
Organic carbon	%	0.87	0.79
P	mg 100 g^{-1} of soil	86.8	79.6
K		189.7	194.5
Mg		63	65
Fe	mg kg^{-1} of soil	1510	2236
Zn		10.6	13.0
Mn		348	433
Cu		4.4	5.5
B		1.2	1.1

* Soil samples were analyzed at the Regional Chemical and Agricultural Station in Rzeszów.

The agronomic category of the tested soil was marked as heavy, valuation class IV (sum of fractions below 0.02 mm: 37.54%) (Table 13).

Table 13. The granulometric composition of the soil.

Division into fractions according to PN-R-04033								
2.0–1.0	1.0–0.5	0.5–0.25	0.25–0.10	0.10–0.05	0.05–0.02	0.02–0.005	0.005–0.002	<0.002
Percentage of mechanical fractions with a diameter in mm								
0	1.06	2.01	2.24	16.98	40.17	25.6	6.56	5.37

Source: Own elaboration based on soil tests carried out by the Chemical and Agricultural Station in Rzeszow.

3.6. Fruit Quality Assessment

Fruit mass losses were determined after 24 h of storage at 10 °C. The test was performed 3 times for each experimental object. A laboratory scale (accuracy 0.01 g) was used for the measurements [38].

The weight of 1000 raspberry fruits was determined using a laboratory scale with an accuracy of 0.01 g. The fruits were counted and then weighed. The assay was repeated three times for each harvest date, cultivar, and fertilization combination.

Fruit strength properties were determined using a CT3 texture meter. The forces needed to permanently distort the structure of a compound fruit as a result of squeezing and tearing, i.e., binding individual drupes into a compound fruit, were determined [38].

The yield of raw juice from fresh raspberry fruit was determined. Juice yield was expressed in ml per 1 kg of fresh fruit. The determination was made using a fruit press. The pressing process lasted 10 min for each sample. Juice was separated from the solid fraction on a sieve with a mesh size of 1.5 × 1.5 mm. The separation process lasted 60 min, followed by the measurement of the juice content in the samples [38].

Fruit strength during transport was assessed on a 5-point scale, where

- Fruits without visible structure damage were rated at 5 points;
- A few pieces of slightly damaged fruit—4 points;
- Half of the fruit structure is damaged—3 points;
- Most damaged and rotting processes started—2 points;
- Rotting and mold development on damaged fruit—1 point [39].

The dry mass of raspberry fruit was determined after the evaporation of water from fresh fruit. The fruit weight of 1 sample intended for determination was 1 kg. The determinations were made on 3 harvest dates. The percentage content of dry matter was calculated using the dryer method [38]. The organoleptic evaluation was carried out according to a 6-point scale for the following characteristics: taste, smell, color, shape, appearance, and consistency [39].

The taste of fruit was determined on the basis of a 5-point scale, where: very sweet—5; sweet—4; slightly sweet—3; sour—2; very sour—1 [34]. The smell of fruit was assessed on the basis of a 4-point criterion: typical raspberry flavor—very distinct—5 points; clear raspberry flavor—4 points; slightly distinct but without foreign smells—3 points; slightly distinct, with the smell of mold and bacteria—2 points [38]. Fruit color was determined according to a 4-point scale: very intense color—5 points; intense—4 points; partially red—3 points; green—2 points [39]. The fruit shape was determined on the basis of a 5-point scale: shape typical for the cultivar—5 points; very slightly deformed—4; slightly deformed—3; clearly deformed—2; not developed—1 [34]. The appearance of the fruit was determined on the basis of a 4-point scale: typical appearance for the cultivar (without signs of disease)—5 points; very slightly affected by diseases—4; slightly affected by diseases—3; heavily affected by diseases—2 [34]. The consistency of the fruit was determined on the basis of a 5-point criterion: very firm (hard) consistency—5 points; firm—4 points; slightly firm—3 points; soft—2 points; very soft with signs of juice spillage—1 point [38].

The organoleptic evaluation was carried out on a group of 12 properly trained people. The results of an organoleptic evaluation of the raspberry by a group of trained people can provide valuable information on sensory preferences and the evaluation of fruit quality. The results can be used for further improvement of raspberry breeding, selection of the best cultivars, or improvement of raspberry cultivation, harvesting, and storage processes in order to ensure the highest quality of fruit for consumers [38].

3.7. Statistical Analysis

The test results were statistically calculated and obtained by variance analysis (ANOVA), SAS 9.2 2008 [39], and multiple Tukey's *t*-tests at the significance level of $p_{0.05}$. Multiple comparison tests of Tukey's *t*-tests enable a detailed comparison of mean values by statistically separating individual starting groups of quantities (groups of 'a', 'b', and 'c' sizes) and determining a smaller difference in mean values, which are marked as LSD [40].

4. Discussion

4.1. Influence of Fertilization on the Size and Quality of Fruit Yield

The yield of raspberry fruit depends to a large extent on the course of the weather: low temperatures in winter, drought in spring and early summer, as well as the age of the plantation [31]. The results obtained in the experiment were strongly influenced by the weather conditions in 2020, namely heavy hail in the first decade of May, which caused damage to the tops of shoots and flower buds. In addition, the spring was very wet, which favored the infection of raspberry shoots by fungal diseases causing shoot dieback [41].

The chemical composition of fruits depends not only on genetic conditions and the age of plants but also on agrochemical factors, mainly fertilization [42,43]. In this study, the highest yield level was obtained at a dose of 135 kg N·ha^{-1}, both for the 'Laszka' and 'Glen Ample' cultivars. Research conducted in Scotland [44] showed that higher doses of nitrogen increase the yield in the first and second years of raspberry cultivation but do not affect the yield in subsequent years, and the reaction to nitrogen fertilization depends on the age of the plant. Increasing the doses of N (0, 50, 100, 200, and 400 kg ha^{-1}) in the cultivation of raspberries in Hungary [45] resulted in an increase in yields but also a smaller fruit size. Similar results were obtained in southern Brazil on the autumn red cultivar Bliss [46]. They obtained higher yields at a nitrogen dose of 200 or 300 kg ha^{-1} than at 100 kg ha^{-1}, while the yields between plants that received 200 and 300 ha^{-1} were at a similar level, which indicates that fertilization exceeding the needs of plants may not have a positive effect on yields. Different results were obtained by Heiberg [47], who conducted research on the 'Veten' cultivar in Norway. The author showed that a high dose of nitrogen (178 kg N ha·ha^{-1}) did not increase the yield compared with a low dose of N fertilizer (40 kg N ha·ha^{-1}). The lack of effect of the dose of N on the yield and quality of fruit was also observed by scientists conducting an experiment with the red cultivar 'Meeker' in north-western Washington (USA) [48]. According to the authors, this could be related to the mineralization of nutrients in the soil and the use of nutrient reserves accumulated in the plant. The effect of fertilization with 4 doses of N (0, 60, 120, and 240 kg N ha^{-1}) and 3 doses of P (0.43 and 86 kg P/ha) on the yield of raspberry cultivar Heritage was also assessed [49]. The authors showed that after application of nitrogen at a dose of 240 kg N ha^{-1}, the highest vegetative growth of raspberry shoots, as well as yielding, occurred. They found no effect of P application or N-P interaction. Fertilization with solutions consisting of five macronutrients (N, P, K, Ca, and Mg) applied in three different doses (0 mg L^{-1}, control, and 10× control) was evaluated by Spiers et al. [50] on the 'Dormanred' cultivar. The application of a 10-fold dose of N resulted in a high concentration of Fe in the leaves but lower concentrations of Ca and Mg in the leaves. The high dose of P increased the content of P, K, and Cu in the leaves but inhibited Ca uptake. A 10-fold K fertilization inhibited the uptake of Ca and Mg but increased the content of P, K, Fe, and Cu in the leaves. High-Ca fertilization increased the content of P in leaves and decreased the uptake of Mg and Mn. A 10-fold dose of Mg increased the Mg content in the leaves but decreased the Ca content. The content of microelements and heavy metals in raspberry fruits of the Willamette cultivar on organic and conventional plantations was assessed by Serbian scientists [51]. Their content was arranged in the following order: Mn > Fe > Zn > Cu > Ni > Cr > C. The authors did not find a significant difference in the concentration of the tested elements in raspberry fruits from organic and conventional cultivation, except for the statistically proven Fe content in organic raspberries. According to Lu et al. [43], an increase in the level of nitrogen fertilization as well as an optimal level of hydration provide plants with a higher yield. The authors observed an increase in yields of the 'Norna' and 'Veten' cultivars as a result of irrigation by nearly 52% compared with natural precipitation. Fertilization of both tested cultivars with a dose of 120 kg N·ha^{-1} turned out to be the most justified. In addition, irrigation significantly increased the fruit yield and the weight of 100 berries, as well as the intensity of leaf assimilation and transpiration. Similar results were also obtained by Treder [52] and Koszański et al. [53].

In addition, raspberry fruits are characterized by anticancer properties, as compounds contained in raspberries, such as ellagitannins, can inhibit the growth of cancer cells and have antimutagenic properties. Moreover, raspberries contain natural sugars and fiber that can help regulate blood sugar levels. Therefore, raspberry fruit may be beneficial for people with diabetes or problems with blood sugar control. It is suggested that consumption of raspberry fruit may be beneficial for the health of the heart and blood vessels. Components contained in raspberries, such as anthocyanins, can lower blood pressure and reduce the risk of cardiovascular diseases. Another beneficial feature of this species is that it aids in digestion. Raspberries are also beneficial for the digestive system. The fiber contained in them can aid digestion, improve intestinal peristalsis, and prevent constipation. It is worth noting that the effects and health benefits of raspberries may vary depending on individual health conditions and consumption. It is always a good idea to consult your doctor or nutritionist before incorporating larger amounts of raspberries into your diet, especially if you have any specific health needs [12,19].

Analyzing the weight of 1000 raspberry fruits, it can be concluded that the tested cultivars differed in the weight of individual fruits, and the use of differentiated nitrogen fertilization against the background of constant phosphorus-potassium fertilization resulted in a significant increase in fruit weight, which corresponds to the results of other authors [54]. In addition, it was observed that with increasing nitrogen doses, both 'Laszka' and 'Glen Ample' showed a significant increase in the weight of 1000 fruits, which in the case of 'Laszka' was 20.8% higher than that of 'Glen Ample'. An increase in the weight of 1000 fruits in relation to differentiated nitrogen fertilization was also observed by Rebanel et al. [54], Treder [52], and Koszański et al. [53].

4.2. Influence of Cultivars on Fruit Yield and Quality

Genetic features played an important role in determining the yield and fruit quality of the tested raspberry cultivars through yield potential, fruit size and shape, their taste and aroma, rheological features, such as resistance to damage and crushing, or post-harvest features [31,32].

Genetic characteristics can determine the natural productivity potential of raspberries. Some cultivars of this species may have genetic traits that favor better flowering and fruit set, larger fruit sizes, or greater overall fruit production, resulting in increased yields. In this study, the 'Glen Ample' cultivar had a significantly higher yield than the 'Laszka' cultivar, which is confirmed by Koszański's et al. research [53].

Genetic features can affect the size and shape of raspberry fruit. Cultivars with specific genetic characteristics can produce larger or smaller fruits, and their shapes can vary significantly. These features may affect the market value and consumer preferences for raspberries. For example, on the European dessert market, traditional cultivars bearing fruit on last year's shoots (summer raspberries) are preferred, which include both tested cultivars and cultivars bearing fruit on this year's shoots (autumn raspberries). The former yields in June–July; the latter ripens in late summer, from August to October. Both groups of cultivars are suitable for organic cultivation, allowing a continuous supply of fresh raspberries from mid-June to October. Although the traditional raspberry is less popular in organic cultivation due to the fact that it is attacked by diseases and pests [52,54]. Studies by numerous authors [7,9,12,14] suggest that consumption of raspberry fruit may have a beneficial effect on heart health. Anthocyanins and flavonoids may help lower blood pressure, reduce LDL (bad) cholesterol, and reduce inflammation in the circulatory system. Due to the presence of antioxidants, consumption of raspberry fruit may have a beneficial effect on the body's ability to fight oxidative stress and delay cell aging. However, the biological value of the raspberry may differ depending on the cultivar [12–14,19].

Raspberry cultivars with dessert fruit, such as 'Glen Ample', suitable for long-distance transport, should be of high quality. The 'Glen Ample' cultivar showed a higher value of the maximum load compared with the 'Laszka' cultivar. Retail chains prefer light-colored fruit that does not darken after harvesting. According to Król et al. [36], among raspberry cultivars bearing fruit on two-year-old shoots, the cultivars 'Glen Ample' and 'Benefis' had the highest fruit yield.

Furthermore, genetic characteristics may influence the post-harvest properties of raspberries, such as their shelf life, firmness, and susceptibility to rotting. Cultivars with improved genetic characteristics may have a longer shelf life, a firmer texture, and better overall post-harvest quality, which can improve marketability and consumer satisfaction [26,27,35]. In the tests carried out, the cultivar 'Laszka' showed greater resistance to crushing. No similar studies have been found in the available literature.

4.3. Influence of Weather Conditions on Fruit Yield and Quality

Meteorological conditions in the summer-autumn-winter period can have a significant impact on the overwintering of two-year-old raspberry shoots. Factors that may affect the ability of raspberries to survive during this period are air temperature, precipitation, air humidity, light, and insolation. The temperature has a significant impact on the growth, development, and yield of the raspberry. This species grows best in moderate temperatures, where the air temperature is around 20–25 °C during the day and does not fall below 15 °C at night. Low temperatures can delay the development of plants, and high temperatures can negatively affect flowering and fruit quality. Temperature is crucial for the raspberry flowering process. Too high or too low air temperatures can affect the efficiency of flowering, pollination, and fruiting [27,31]. Optimal temperatures during the raspberry flowering period are usually between 15 and 25 °C. Air temperature affects the rate of ripening of raspberry fruit. Warmer temperatures speed up the ripening process, which can result in a shorter period between flowering and harvesting. However, too high temperatures can lead to excessive ripening, reduced quality, and a shortened shelf life of fruit [26,28]. The air temperature can also affect the quality of the Raspberry. Low temperatures are a key factor affecting the overwintering of raspberry shoots. Depending on the cultivar, raspberries may be more tolerant of cold temperatures, but they generally tolerate cold winter conditions well. However, extreme frosts can damage shoots and have a negative impact on overwintering. In addition, different raspberry cultivars may have different temperature requirements [31]. Therefore, it is important to adapt the cultivation of raspberries to the appropriate climatic conditions and monitor the temperature to ensure optimal conditions for growth, yield, and fruit quality. In the research conducted, in the year of harvest, high temperatures often occurred, exceeding the long-term average in August by up to 5 °C. This could have contributed to poorer flowering and fruit filling, a poorer response of plants to nitrogen fertilization, and, as a result, poorer juice yield and poorer consumption quality of fruit [26–28].

The optimal amount of rainfall in the summer and autumn–winter periods can also affect the overwintering of raspberry shoots. Irrigation of the roots in the summer season provides the plant with adequate moisture and water supply, which is important for overwintering. Also, high air humidity in the autumn and winter can contribute to the occurrence of fungal diseases that can weaken raspberry shoots and have a negative impact on overwintering. Finally, light conditions, i.e., proper exposure to light in the summer and autumn–winter periods, are important for their proper growth, development, and overwintering. Proper insolation favors the accumulation of nutrients and increases the resistance of raspberries to extreme temperatures [31].

The raspberry also needs the right amount of water, especially during flowering and fruit ripening. However, too much or too little rainfall can negatively affect the yield of raspberries and their quality. Excessive humidity can promote the development of fungal diseases such as powdery mildew, while drought can lead to insufficient hydration of plants [27,31]. Rainfall can create favorable conditions for the development of fungal diseases such as gray mold or rust. A moist environment also favors the reproduction of pests such as aphids and spider mites. This can lead to plant damage, reduced yields of fruits, and fruits of poor quality. To properly manage rainfall in raspberry cultivation, it is essential to monitor the weather and manage irrigation properly. Taking care of proper soil drainage, the use of irrigation systems, and plant protection products can help minimize the negative effects of excessive rainfall on the yield and quality of raspberries [27,30]. In the research conducted, irrigation of plants was not used, and in several periods of plant growth, there were significant water shortages. This could affect both the yield and the health and quality of the fruit. This is confirmed by Winiarska's research [31].

The resistance of the raspberry to weather conditions may vary depending on the cultivar and local climatic conditions. Appropriate cultivation practices should be adapted and weather conditions monitored to optimize the overwintering of raspberry shoots [31].

According to Krawiec and Rybczyński [41], the yield is largely affected by weather conditions, which cause damage to entire plants or inflorescences.

4.4. Commodity Characteristics and Fruit Quality

The most important aspects that are taken into account in the commodity evaluation of fruit are its external appearance, consistency, taste, aroma, and juice content. In addition, the fruit should be clean and free of contaminants such as soil, insects, mold, or other foreign substances and should have sufficient durability to survive transport and storage without major damage [27]. The above parameters are general and may vary depending on specific market requirements or quality standards set by relevant institutions or organizations [31]. It is also important to follow the principles of sustainable management, including nitrogen fertilization, to ensure healthy and organically grown raspberry fruits [28].

Raspberry fruit should also be fresh, juicy, and of good quality to meet consumer expectations and provide health benefits, i.e., vitamins, minerals, antioxidants, and fiber, which attract consumers looking for safe and healthy food [13,14,19]. Raspberry is also low in calories and can be part of a healthy diet. Consumers care about natural and fresh products, especially when it comes to fruit. *R. idaeus* is seen as a natural, seasonal fruit that can be eaten in its original form.

One of the features is the universality of the application. Raspberry fruits can be eaten in many different ways—as an independent fruit, an addition to desserts, or an ingredient in cocktails, jellies, jams, or casseroles. This versatility of application attracts various groups of consumers [31].

Therefore, commodity characteristics are important aspects of assessing the quality of raspberry (*R. idaeus* L.) fruit. The research shows that the key commodity characteristics that affect the quality of raspberry fruit are

- Color: Raspberry fruit should have an attractive, uniform color without spots, discoloration, or signs of immaturity [19].
- Size and shape: Raspberry fruit should have regular, well-formed, and compact berries. Abnormal sizes may indicate developmental issues [31,54].
- Firmness: Raspberry fruits should be firm yet delicate to the touch. Softness may indicate overripeness or damage.
- Taste and aroma: Raspberry fruit should have a distinct, balanced taste that is sweet and sour, accompanied by an intense, characteristic aroma [14].
- Juiciness: Raspberry fruit should be juicy, with ample amounts of juice. Dryness or a lack of juiciness may indicate immaturity or low quality.

– Durability and freshness: Raspberry fruit should be fresh, durable, and retain its sensory properties for an extended period. They should not be overripe, crushed, moldy, or show signs of deterioration [31].

Fruit mass losses during 24 h storage differed depending on fertilization and cultivar. 'Glen Ample' was characterized by a greater loss of fresh fruit weight. However, this did not have a significant effect on the examined feature. In a study by Krawiec et al. [41] on raspberries bearing fruit on one-year-old shoots, the mass loss was 1.3% for the 'Polka' cultivar and 0.4% for the 'Polana' cultivar. Weight loss on stored fruits and vegetables was observed by Nunes and Emond [55]. There is a significant correlation between weight loss and the visual quality of each fruit and vegetable. It was also observed that with an increase in weight loss during storage, shelf life also decreases, and in addition, there is an increase in wilting, shrinking, and browning of fruits [27,28].

Raspberry fruits have low mechanical resistance in their tissues and a high water content. Firmness is considered a good indicator of the appropriate quality of the picked fruit. It indicates the suitability of fruits for harvesting, transport, consumption, or freezing, as well as for identifying fruits infected with fungal diseases [28,41,56]. The assessment of raspberry fruit firmness was carried out by Italian authors [57,58], examining three cultivars: 'Heritage', 'Glen Magna', and 'Tulameen'. They observed a marked decrease in firmness after 3 days of storage of Heritage at 3 °C (−32%) and only a slight decrease in firmness in 'Glen Magna' and 'Tulameen'. On the 6th day of storage, a decrease in firmness was observed in all tested cultivars, and in the final shelf life (after 8 days of storage), all fruits had a significant loss of density and firmness (−43% and −48%). A clear decrease in the loss of firmness of 'Erica' raspberries after 4 days of storage at 4 °C was also observed by Giovanelli et al. [57]. However, its maximum reduction was achieved when fruit was packed using plastic with a high (LDPE/EVOH/LDPE) gas barrier and a biopolymer film (PLA) with an average gas barrier.

The rheological properties of raspberries are important from the point of view of product quality, especially in the context of transport, storage, and processing. They can also be used to assess the ripeness of raspberry fruits and identify changes in their structure during storage and processing [59]. The tests showed that higher values of the maximum load indicate greater strength in the fruit. The work refers to the energy needed to cause deformation in raspberry fruit. Higher values of work indicated greater flexibility and the ability of raspberry fruit to absorb energy during deformation [28]. The final load is the force at which the raspberry fruit reaches its final deformation or breakage. It reflects the point at which the fruit loses its elasticity and becomes irreversibly deformed.

Varietal properties differentiate the value of rheological features. The 'Glen Ample' cultivar showed a higher maximum load value. The reaction of the tested cultivars to fertilization was varied. However, increasing doses of nitrogen did not significantly affect the rheological evaluation of the fruit. Balanced nitrogen fertilization had no significant effect on the maximum load [36,60–64]. This proves the possibility of an earlier introduction of fresh fruit into commercial circulation. The optimal aroma, firmness, size, and color of the fruit were obtained by picking raspberries from the plantation at the appropriate stage of maturity, i.e., picking them many times during the season. Firmness is considered a good indicator of the appropriate quality of the picked fruit. According to Rybczyński et al. [42], the force of fruit detachment is a varietal feature and depends on the size and shape of the flower base, on the degree of fruit ripeness, and sometimes on weather conditions during the harvest period.

Availability is an important commodity feature of raspberry fruit. *R. idaeus* fruit is available on the market most of the year, both as fresh fruit and as processed products. This makes them more accessible to consumers, who can enjoy them for most of the year [57].

Evaluation of raspberry fruit quality should take into account both sensory and rheological characteristics as well as chemical composition. The conducted research indicates the need for a holistic approach to quality assessment, combining organoleptic and rheological assessment with chemical analyses.

4.5. Norms and Standards of Fruit

In the case of the raspberry (*R. idaeus* L.), there are many norms and quality standards that are used in different regions and markets [57]. Here are some of the main norms and quality standards specific to the raspberry:

Marketing Standards: Many countries develop marketing standards that set minimum requirements for the quality of raspberries. These standards may include criteria such as size, shape, color, degree of maturity, presence of defects (e.g., mechanical damage, rot), and physicochemical parameters (e.g., sugar content, acidity). However, for international trade in raspberries, general quality standards such as ISO 9001 (Quality Management Systems) [60] and ISO 22000 (Food Safety Management Systems) [62] may be used. The international ISO 9001 standard is one of the most popular standards, whose compliance is confirmed by external certifications. The number of ISO 9001 certificates issued in the world is incomparably greater than the number of other types of management system certificates. According to the ISO report for 2020, the number of ISO 9001 certificates significantly exceeds the number of all other certificates combined. These standards are general food quality and safety standards that may apply to raspberries and other food products. In addition, there are also industry and national standards that may cover raspberries and specify detailed requirements for quality, safety, and other parameters. It is important that raspberry producers and exporters familiarize themselves with the applicable norms and standards in their country or target market in order to meet commercial requirements and ensure the high quality of their products [57,62–64].

Industry Standards: In some countries, there are also industry standards developed by farming organizations or raspberry associations. Industry standards for raspberry fruit may vary by country and region but are generally intended to establish minimum requirements for quality, grading, packaging, and labeling of raspberry fruit. Industry standards for fruit and vegetables still exist in the European Union. They were established to ensure the quality, safety, and fairness of intra-EU trade in these products. The main provisions on industry standards for fruit and vegetables can be found in Regulation (EC) No 543/2011 [65]. These standards define the quality and shape requirements for various types of fruit and vegetables. They also specify minimum requirements for maturity, purity, damage, calibration, and packaging. The standards also include the classification of products based on their quality, with the highest class being Extra, followed by Classes I and II, respectively. The introduction of industry standards aims to facilitate trade in fruit and vegetables within the EU by ensuring consistency in the quality and labeling of products. These standards are also intended to protect consumers from poor-quality or unsafe products. However, it is worth noting that there have been some changes in the approach to industry standards at EU level in recent years. In some cases, less restrictive requirements for the shape and appearance of fruit and vegetables are introduced to increase acceptance of cultivars and reduce food waste. Nevertheless, there are still a number of industry standards that must be followed in order to trade fruit and vegetables within the EU.

Industry standards of the American Particular Food Association (USDA) are set by the United States Department of Agriculture (USDA), which sets quality standards for many agricultural products, including fruits and vegetables. The USDA establishes quality, classification, packaging, and labeling guidelines for raspberries sold in the US market [57]. Australia has standards set by organizations such as Horticulture Innovation Australia (HIA) and the Australian Raspberry Growers Association (ARGA). These standards include quality, classification, packaging, labeling, hygiene, and environmental requirements.

It is important that raspberry producers and traders adhere to the relevant industry standards to ensure high product quality and compliance with market requirements. The choice of standards should take into account local legal regulations and consumer expectations in a given market [57]. The purpose of industry standards is to ensure uniform quality and safety of raspberry products [5]. Many countries also have general food quality standards that include the raspberry as one of many foods. These standards can regulate aspects such as hygiene, freshness, purity, chemical and microbiological safety, labeling, and consumer information [61,62].

4.6. Trends in the Cultivation, Breeding, Nutritional Tradition, and Market of the Raspberry

In recent years, several trends in the cultivation of the raspberry (*R. idaeus* L.) have been observed. Here are some of them:

(a) Organic farming: An increasing number of raspberry producers are switching to organic farming. Organic farming involves using natural methods and minimizing the use of pesticides and chemical fertilizers. This approach aims to produce healthier fruit with less environmental impact and greater respect for biodiversity [6].

(b) Cultivation under cover: Many raspberry plantations use cover systems, such as foil tunnels or greenhouses. Cultivation under cover allows you to control weather conditions, extend the growing season, protect against frost, pests, and diseases, and increase yields [6,63].

(c) Breeding of new cultivars: In recent years, significant progress has been made in the breeding of new raspberry cultivars. Breeders are trying to develop cultivars with higher yields, larger fruits, better resistance to diseases and pests, a longer harvesting period, excellent taste, and an attractive appearance. New cultivars of raspberries are aimed at meeting consumer expectations and improving the profitability of cultivation [5,63].

(d) Automation and technology in production: In order to increase the efficiency and precision of production, more and more raspberry producers are using modern technological solutions. Automated systems of irrigation, harvesting, sorting, and packaging of fruit contribute to increasing productivity, improving fruit quality, and reducing production costs [6,31,64].

(e) Sustainable cultivation practices were developed in response to the growing interest of consumers in ecological products and sustainable development. Raspberry producers are increasingly using sustainable practices in their crops. These include minimizing water consumption, optimizing the use of fertilizers, using natural pest and disease control methods, and monitoring and minimizing the impact of production on the natural environment [5,6,64].

These trends in raspberry cultivation and breeding are aimed at improving the quality and efficiency of production, meeting the growing demand for healthy and ecological products, and increasing resistance to diseases [5,6,31]. Food trends. In recent years, interest in healthy eating and natural products has increased. Raspberry proper fits perfectly into these trends, which translates into their greater importance on the consumer market [57].

Market trends related to raspberry (*R. idaeus*) may vary depending on the region and consumer preferences [57]. Here are some general trends you may notice:

Increased interest in healthy eating: Consumers are increasingly interested in healthy and natural foods. Raspberries are rich in vitamins, minerals, antioxidants, and fiber, which makes them an attractive choice for people who are conscious of a healthy diet. Encouraging the consumption of fruit fresh, unprocessed, or used as an ingredient in healthy snacks and food products may contribute to an increased demand for raspberry fruit. Increasing popularity of ecological products: Consumers care about conscious choice and care for the environment. The increase in demand for raspberries from organic farming may be related to the preference for products without artificial pesticides and fertilizers. Customers are looking for raspberries with organic certificates or from local, sustainable crops.

Raspberries can be used in a variety of processed foods, such as jams, syrups, juices, ice cream, and even cosmetics. Processed raspberry products can offer added value and flavor cultivars for consumers. Companies can focus on innovative ways of using raspberries to create attractive and differentiated products for the market [57,63].

Seasonality and local production: Raspberries are often available in specific seasons, which can affect their value and market availability. Local production of raspberries, especially during the season, may be appreciated by consumers who prefer fresh fruit [57,65].

5. Conclusions

Genetic features differentiated the tested cultivars. The cultivar 'Glen Ample' had a higher yield and juice yield, while the cultivar 'Laszka' had a higher dry weight of fruit. Organoleptic features did not significantly differentiate the tested cultivars, except for their color. The 'Laszka' cultivar was distinguished by a better, more intense color of fruit, but only on the first date of harvest. Rheological features of raspberry fruits, such as maximum load, work load, and final load, refer to their mechanical and textural properties. The cultivar 'Glen Ample' showed a higher resistance to deformation and crushing, and the cultivar 'Laszka', with a higher content of dry matter, showed a higher resistance to transport.

In general, balanced fertilization had a beneficial effect on *R. idaeus* fruit yield and quality. Increasing nitrogen fertilization up to 135 kg N ha^{-1}, against the background of constant phosphorus-potassium fertilization, resulted in a successive increase in fresh fruit yield but, on the other hand, a decrease in their dry matter content.

The cultivation of this species with balanced fertilization led to the production of fruits with good sensory and rheological properties. The successive increase in nitrogen fertilization against the background of appropriate phosphorus-potassium fertilization did not deteriorate the quality of the raw material, which is the fresh raspberry. The use of appropriate doses of fertilizers can improve the organoleptic characteristics of raspberry fruit, such as taste, aroma, color, appearance, and consistency. Sustainable fertilization may affect the functional properties of raspberry fruits as well as their sensory and rheological properties, resistance to transport, and storage stability.

Raspberry cultivars differed in response to different nitrogen fertilizations. Cultivar 'Laszka' responded with a significant increase in the weight of 1000 fruits to nitrogen supply and responded better to this factor of the experiment, while 'Glen Ample' turned out to be less sensitive to this component.

Optimal nitrogen fertilization should take into account the balance between the needs of plants and minimizing the negative impact on the environment. It is important to include other nutrients in addition to nitrogen, such as phosphorus, potassium, and micronutrients, to provide plants with comprehensive fertilization. The individual approach to nitrogen fertilization should be adapted to the varietal diversity and growing conditions.

This will allow you to achieve optimal growth, yield, and fruit quality. The dates of fruit harvest determined significantly the weight of 1000 fruits, their dry matter content, and their resistance to transport. The highest value of these features was obtained at the first and earliest date of harvest.

The conclusions suggest that proper fertilization is a key factor affecting the quality of raspberry fruit and should be considered in cultivation practices to ensure optimal results, both in economic and health terms.

Author Contributions: Conceptualization, B.S., P.B. and P.P.; methodology, B.S., D.S. and B.K.-M.; software, D.S.; validation, P.B., B.K.-M. and P.P.; formal analysis, B.S.; investigation, P.P.; resources, P.B.; data curation, D.S.; writing—original draft preparation, P.B.; writing—review and editing, B.S. and B.K.-M.; visualization, P.P.; supervision, B.S. and B.K.-M.; project administration, B.S.; funding acquisition, B.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No new data were created in these studies.

Acknowledgments: We thank the University of Life Sciences in Lublin for administrative and technical support in conducting this research.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hummer, K.E.; Janick, J. Rosaceae: Taxonomy, economic importance, genomics. In *Genetics and Genomics of Rosaceae*; Springer: New York, NY, USA, 2009; pp. 1–17.
2. Krauze-Baranowska, M.; Majdan, M. Raspberries—A source of therapeutically valuable secondary metabolites and vitamins. *Panacea* **2009**, *1*, 14–15.
3. Krauze-Baranowska, M.; Głód, D.; Kula, M.; Majdan, M.; Hałasa, R.; Matkowski, A.; Kozłowska, W.; Kawiak, A. Chemical composition and biological activity of *Rubus idaeus* shoots—A traditional herbal remedy of Eastern Europe. *BMC Complement. Altern. Med.* **2014**, *14*, 480. [CrossRef] [PubMed]
4. Baranowska, A.; Mystkowska, I.; Zarzecka, K.; Gugała, M. Cenne owoce maliny właściwej (*Fructus Rubi idaei*). *Herbalism* **2017**, *3*, 70–79. (In Polish) [CrossRef]
5. Titirică, I.; Roman, I.A.; Nicola, C.; Sturzeanu, M.; Iurea, E.; Botu, M.; Sestras, R.E.; Pop, R.; Militaru, M.; Ercisli, S.; et al. The Main Morphological Characteristics and Chemical Components of Fruits and the Possibilities of Their Improvement in Raspberry Breeding. *Horticulturae* **2023**, *9*, 50. [CrossRef]
6. Wróblewska, W.; Pawlak, J.; Paszko, D. Influence of factors on the yield of two raspberry varieties (*Rubus idaeus* L.) and economic results. *Acta Sci. Pol. Hortorum Cultus* **2020**, *19*, 63–70. (In Polish) [CrossRef]
7. Aprea, E.; Biasioli, F.; Gasperi, F. Volatile compounds of raspberry fruit: From analytical methods to biological role and sensory impact. *Molecules* **2015**, *20*, 2445–2474. [CrossRef]
8. Dujmović Purgar, D.; Duralija, B.; Voća, S.; Vokurka, A.; Ercisli, S. A comparison of fruit chemical characteristics of two wild grown Rubus species from different locations of Croatia. *Molecules* **2012**, *17*, 10390–10398. [CrossRef]
9. Horuz, A.; Korkmaz, A.; Karaman, M.R.; Dizman, M.; Turan, M. The evaluation of leaf nutrient contents and element ratios of different raspberry varieties. *J. Food Agric. Environ.* **2013**, *11*, 588–593.
10. Quintanilla, A.; Mencia, A.; Powers, J.; Rasco, B.; Tang, J.; Sablani, S.S. Developing vacuum-impregnated dehydrofrozen red raspberries with improved mechanical properties. *Dry. Technol.* **2022**, *40*, 299–309. [CrossRef]
11. Cosme, F.; Pinto, T.; Aires, A.; Morais, M.C.; Bacelar, E.; Anjos, R.; Ferreira-Cardoso, J.; Oliveira, I.; Vilela, A.; Gonçalves, B. Red Fruits composition and their health benefits—A review. *Foods* **2022**, *11*, 644. [CrossRef]
12. Du, X.; Qian, M. Flavor chemistry of small fruits: Blackberry, raspberry, and blueberry. In *Flavor and Health Benefits of Small Fruits*; American Chemical Society: Washington, DC, USA, 2010; pp. 27–43.
13. Lopez-Corona, A.V.; Valencia-Espinosa, I.; González-Sánchez, F.A.; Sánchez-López, A.L.; Garcia-Amezquita, L.E.; Garcia-Varela, R. Antioxidant, anti-inflammatory and cytotoxic activity of phenolic compound family extracted from Raspberries (*Rubus idaeus*): A general review. *Antioxidants* **2022**, *11*, 1192. [CrossRef] [PubMed]
14. De Ancos, B.; González, E.M.; Cano, M.P. Ellagic acid, vitamin C, and total phenolic contents and radical scavenging capacity affected by freezing and frozen storage in raspberry fruit. *J. Agric. Food Chem.* **2000**, *48*, 4565–4570. [CrossRef]
15. Mullen, W.; Stewart, A.J.; Lean, M.E.; Gardner, P.; Duthie, G.; Crozier, A. Effect of freezing and storage on the phenolics, ellagitannins, flavonoids, and antioxidant capacity of red raspberries. *J. Agric. Food Chem.* **2002**, *50*, 5197–5201. [CrossRef] [PubMed]
16. Bobinaitė, R.; Viškelis, P.; Venskutonis, P.R. Variation of total phenolics, anthocyanins, ellagic acid and radical scavenging capacity in various raspberry (*Rubus spp.*) cultivars. *Food Chem.* **2020**, *132*, 1495–1501. [CrossRef]
17. Jakobek, L.; Seruga, M.; Novak, I.; Medvidovic-Kosanovic, M. Flavonols, phenolic acids and antioxidant activity of some red fruits. *Dtsch. Lebensm. Rundsch.* **2007**, *103*, 369–377.
18. Wang, S.Y.; Chen, C.T.; Wang, C.Y. The influence of light and maturity on fruit quality and flavonoid content of red raspberries. *Food Chem.* **2009**, *112*, 676–684. [CrossRef]
19. Khoo, H.E.; Azlan, A.; Tang, S.T.; Lim, S.M. Anthocyanidins and anthocyanins: Colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food Nutr. Res.* **2017**, *61*, 1361779. [CrossRef]
20. Viskelis, P.; Rubinskiene, M.; Bobinaite, R.; Dambrauskiene, E. Bioactive compounds and antioxidant activity of small fruits in Lithuania. *J. Food Agric. Environ.* **2010**, *8*, 259–263.
21. Vrhovsek, U.; Giongo, L.; Mattivi, F.; Viola, R. A survey of ellagitannin content in raspberry and blackberry cultivars grown in Trentino (Italy). *Eur. Food Res. Technol.* **2008**, *226*, 817–824. [CrossRef]
22. Ponder, A.; Hallmann, E. Phenolics and carotenoid contents in the leaves of different organic and conventional raspberry (*Rubus idaeus* L.) cultivars and their in vitro activity. *Antioxidants* **2019**, *8*, 458. [CrossRef] [PubMed]
23. Burton-Freeman, B.M.; Sandhu, A.K.; Edirisinghe, I. Red Raspberries and their Bioactive Polyphenols: Cardiometabolic and Neuronal Health Links. *Adv. Nutr.* **2016**, *7*, 44–65. [CrossRef] [PubMed]
24. Larrosa, M.; García-Conesa, M.T.; Espín, J.C.; Tomás-Barberán, F.A. Ellagitannins, ellagic acid and vascular health. *Mol. Asp. Med.* **2010**, *31*, 513–539. [CrossRef] [PubMed]
25. Haffner, K.; Rosenfeld, H.J.; Skrede, G.; Wang, L. Quality of red raspberry *Rubus idaeus* L. cultivars after storage in controlled and normal atmospheres. *Postharvest Biol. Technol.* **2002**, *24*, 279–289. [CrossRef]
26. Temocico, G.; Stoian, E.; Ion, V.; Tudor, V. Results regarding behavior of some small fruits under controlled atmosphere conditions. *Rom. Biotechnol. Lett.* **2014**, *19*, 9162–9169.
27. Krüger, E.; Dietrich, H.; Schöpplein, E.; Rasim, S.; Kürbel, P. Cultivar, storage conditions and ripening effects on physical and chemical qualities of red raspberry fruit. *Postharvest Biol. Technol.* **2011**, *60*, 31–37. [CrossRef]

28. González-Orozco, B.D.; Mercado-Silva, E.M.; Castaño-Tostado, E.; Vázquez-Barrios, M.E.; Rivera-Pastrana, D.M. Effect of short-term controlled atmospheres on the postharvest quality and sensory shelf life of red raspberry (*Rubus idaeus* L.). *J. Food* **2020**, *18*, 352–358. [CrossRef]
29. Forney, C.F.; Jamieson, A.R.; Pennell, K.D.M.; Jordan, M.A.; Fillmore, S.A.E. Relationships between fruit composition and storage life in air or controlled atmosphere of red raspberry. *Postharvest Biol. Technol.* **2015**, *110*, 121–130. [CrossRef]
30. Valentinuzzi, F.; Pii, Y.; Mimmo, T.; Savini, G.; Curzel, S.; Cesco, S. Fertilization strategies as a tool to modify the organoleptic properties of Some Biological and Production Features of Fruiting Canes of Ten Raspberry Cultivars (*Rubus idaeus* L.) raspberry (*Rubus idaeus* L.) fruits. *Sci. Hortic.* **2018**, *240*, 205–212. [CrossRef]
31. Winiarska, J. *Some Biological and Production Features of Fruiting Canes of Ten Raspberry Cultivars (*Rubus idaeus *L.). Habilitation*; University of Life Sciences in Lublin: Lublin, Poland, 1992; p. 60. (In Polish)
32. UN/ECE FFV-32; Agricultural Quality Standards (WP.7). UNECE. 2023. Available online: https://unece.org (accessed on 15 May 2023).
33. Danek, J. *Cultivation of Raspberry and Blackberry*; HORTPRESS: Warsaw, Poland, 2009; pp. 7–60. (In Polish)
34. Gacek, E. *List of Fruit Plant Varieties Entered in the National Register in Poland*; Central Research Center for Cultivar Testing in Słupia Wielka: Słupia Wielka, Poland, 2012; pp. 20–34. (In Polish)
35. Kotuła, M.; Kapusta-Duch, J.; Smoleń, S.; Doskočil, I. Phytochemical Composition of the Fruits and Leaves of Raspberries (*Rubus idaeus* L.)—Conventional vs. Organic and Those Wild Grown. *Appl. Sci.* **2022**, *12*, 11783. [CrossRef]
36. Król, K.; Danek, J.; Skrzyński, J. *Raspberry Varieties for Dessert Fruit Production*; Institute of Pomology and Floriculture: Brzezna, Poland, 2010; pp. 13–20. (In Polish)
37. Vinczeffy, I. The effect of some ecological factors on grass yield. In Proceedings of the 10th General Meeting of the European Grassland Federation, Ås, Norway, 26–30 June 1984; pp. 76–79.
38. Czarniecka-Skubina, E.; Nowak, D. *Food Technology. Part 1. Fundamentals of Food Technology*; Format-AB Publishing House: Warsaw, Poland, 2010; ISBN 978-83-891-8435-1. (In Polish)
39. SAS Institute Inc. *SAS/STAT®9.2 User's Guide*; SAS Institute Inc.: Cary, NC, USA, 2008.
40. Koronacki, J. *Statistics, for Students of Technical and Natural Sciences*; Scientific and Technical Publishing House: Warsaw, Poland, 2009; p. 491. (In Polish)
41. Krawiec, P.; Grenda, A.; Rybczyński, R. Evaluation of fertigation efficiency in raspberries of repeating varieties according to the Yara program. *Bull. Assoc. Fruit Grow. Repub. Pol.* **2010**, *1*, 24–27. (In Polish)
42. Rybczyński, R.; Dobrzański, B.; Więźniarska, J. Właściwości mechaniczne owoców maliny. *Acta Agrophys.* **2001**, *45*, 167–175. (In Polish)
43. Lu, Q.; Miles, C.; Tao, H.; De Vetter, L.W. Reduced Nitrogen Fertilizer Rates Maintained Raspberry Growth in an Established Field. *Agronomy* **2022**, *12*, 672. [CrossRef]
44. Lawson, H.M.; Waister, P.D. The response to nitrogen of a raspberry plantation under contrasting systems of management for weed and sucker control. *Hort. Res.* **1972**, *12*, 43–55.
45. Papp, J.; Kobzos-Pápai, I.; Nagy, J. Effect of nitrogen application on yield, leaf nutrient status and fruit chemical composition of raspberry and redcurrant varieties. *Acta Agron. Acad. Sci. Hung.* **1984**, *33*, 337–343.
46. Rizzi, R.; Silvestre, W.P.; Rota, L.D.; Pauletti, G.F. Raspberry production with different NPK dosages in South Brazil. *Sci. Hortic.* **2019**, *261*, 108984. [CrossRef]
47. Heiberg, N. Effect of vegetation control and nitrogen fertilization in red raspberry. *Acta Hortic.* **2002**, *585*, 579–583. [CrossRef]
48. Lu, Q.; Miles, C.; Tao, H.; DeVetter, L. Evaluation of real-time nutrient analysis of fertilized raspberry using petiole sap. *Front. Plant Sci.* **2022**, *13*, 918021. [CrossRef]
49. Ali, L. Pre-harvest factors affecting quality and shelf-life in raspberries and blackberries (*Rubus* spp. L.). Doctoral Thesis, Swedish University of Agricultural Sciences, Alnarp, Sweden, 2012; p. 73.
50. Spiers, J.M.; Braswell, J.H.; Gupton, C.L. Influence of P, K, Ca, and Mg rates on leaf elemental concentration and plant growth of 'Dormanred' raspberry. *Acta Hortic.* **1999**, *505*, 337–342. [CrossRef]
51. Milinković, M.; Vranić, D.; Đurić, M.; Paunović, S.M. Chemical composition of organically and conventionally grown fruits of raspberry (*Rubus idaeus* L.) cv. Willamette. *Acta Agric. Serbica* **2021**, *26*, 83–88. [CrossRef]
52. Treder, W. The effect of irrigation and mulching with black foil on the yield of Canby raspberries. *Zeszyty Nauk Sadowniczych* **1993**, *1*, 27–32. (In Polish)
53. Koszański, Z.; Karczmarczyk, S.; Podsiadło, C.; Herman, B. Effect of irrigation and nitrogen fertilization on the yield of two cultivated raspberry cultivars on light soil. *Folia Horiculture* **2003**, *2*, 246–248. (In Polish)
54. Rebanel, Z.; Przypiecka, M.; Cofta, H. *Irrigation for Yield and Growth of Raspberry Variety Nora*; Works of the Sandinista Institutes and Floriculture: Skierniewice, Poland, 1992; pp. 69–70. (In Polish)
55. Nunes, C.N.; Emond, J.P. Relationship between weight loss and visual quality of fruits and vegetables. *Proc. Fla. State Hortic. Soc.* **2007**, *20*, 235–245.
56. Rybczyński, R.; Dobrzański, B., Jr.; Wieniarska, J. Mechanical properties of raspberry fruit. *Acta Agroph.* **2001**, *45*, 167–175. (In Polish)
57. Giovanelli, G.; Limbo, S.; Buratti, S. Effects of new packaging solutions on physio-chemical, nutritional and aromatic characteristics of red raspberries (*Rubus idaeus* L.) in postharvest storage. *Postharvest Biol. Technol.* **2014**, *98*, 72–81. [CrossRef]

58. Cortellino, G.; De Vecchi, P.; Lo Scalzo, R.; Ughini, V.; Granelli, G.; Buccheri, M. Ready-to-eat raspberries: Qualitative and nutraceutical characteristics during shelf-life. *Adv. Hort. Sci.* **2018**, *32*, 399–406.
59. Borkowski, K.; Jankulovski, N.; Mihajlovski, G.; Momirceski, J. Analysis of market opportunities for raspberry production in the Republic of North Macedonia. *Int. J. Res.* **2020**, *8*, 149–154. [CrossRef]
60. ISO 9001; Quality Management Systems. Available online: https://www.iso.org.pl/uslugi-zarzadzania/wdrazanie-systemow/zarzadzanie-jakoscia/iso-9001/ (accessed on 14 May 2023).
61. Food Safety Management System—ISO 22000—Requirements for All Food Chain Organizations. 2008. Available online: https://www.iso.org.pl/artykuly-i-informacje-dotyczace-systemow-zarzadzania/iso-22000-wymagania/ (accessed on 15 May 2023).
62. Latest ISO Research—Rapid Growth in Popularity of Energy Management System! Available online: www.iso.org.pl/najnowsze-badania-iso (accessed on 14 March 2023). (In Polish)
63. Kala, R. *Elements of Parametric Inference for Naturalists*; Wydawnictwo Akademii Rolniczej: Poznań, Poland, 1993; ISBN 978-83-716-0010-4. (In Polish)
64. Rolbiecki, S.; Rolbiecki, R.; Czekanowski, C. Irrigation as a factor counteracting the effects of drought in raspberry cultivation on sandy soil. *Woda—Środowisko—Obszary Wiejskie* **2005**, *5*, 243–260. (In Polish)
65. European Commission. Commission Implementing Regulation (Eu) No 543/2011 of 7 June 2011 laying down detailed rules for the application of Council Regulation (EC) No 1234/2007 as regards the fruit and vegetables sector and the processed fruit and vegetables sector. *Off. J. Eur. Union* **2011**, *157*, 1–163.