Assessment of economically valuable forms of fruit of the genus *Juglans* for the creation of forest crops in the Voronezh region

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**Abstract.** Taking into account the emerging trend towards temperature increase in the region of the research in recent years, introduction and cultivation of the genus *Juglans* in the Voronezh region is a pressing issue. The paper reviews 4 species of nuts – black walnut, Manchurian, gray and heartnut, which are the most promising for the creation of forest crops, because they are the most resistant to adverse factors in the area of introduction among all species of the genus *Juglans*. Taking into account the specific features and the intense form diversity of nuts of the genus *Juglans*, an assessment scale was proposed and a regional methodology was developed for assessing the quality of fruits. The quality of the fruits of the forms and types of nuts was determined by the total value of the evaluation criteria, taking into account the level of significance of each trait. The trees species which in aggregate have the best resistance to adverse factors and have acceptable quality fruits (EC = 136 and 188) are black walnut and heartnut. It is these types of the genus *Juglans* that are primarily recommended for full reforestation and afforestation in the Voronezh region.

1. Introduction
Nut species of *Juglans* are unique plants of food, medicinal and forestry importance, and therefore, they are widely used in forestry and fruit growing. Given the multifunctional nature of the nut species, they should be used not only as fruit trees, but also for the creation of forest crops, planting, increasing sustainability of plantations and increasing their ecological functions [1]. Adoption of silvoarable agroforestry systems by integrating trees and arable crops on the same land could offer a range of environmental benefits compared with conventional agricultural systems [2].

Nuts species have been used since ancient times because of its immunomodulatory effects, opportunities to create sustainable plantations and increasing plant biodiversity [3,4]. It is noted that nut species of *Juglans* can be actively used to obtain herbal medicines [5], have antioxidant and antibacterial properties [6]. The species under study, in particular black walnut, can be successfully used to create forest crops [7], have good quality of fruit [8] and can regulate the ecological balance in plantations [9] because it has a strong antibacterial effect [10].

The aim of the work is to select valuable types and forms of nuts, resistant to adverse factors, for forest crops creation. The species and forms of nuts of the genus *Juglans*, best in resistance to adverse factors, were determined, and the most economically valuable of them, promising for creating forest crops and landscaping, were selected. Since the main focus of walnut is plantation cultivation in order to produce fruit and wood, the work has examined the species of the genus
Juglans – black walnut, Manchurian walnut, grey walnut, and heartnut, which may be appropriate for the task.

2. Material and methods
In the region under study, most species of the genus *Juglans* [11] have been introduced, but they have a good condition. They bloom annually and bear fruit (five of them) stably. These are walnut (*Juglans regia* L.), Manchurian walnut (*Juglans manshurica* Max.), black walnut (*Juglans nigra* L.), grey walnut (*Juglans cinerea* L.) and heartnut (*Juglans cordiformis* Max.). The objects of the study were fruit-bearing plantations, aged 30-50 years, growing in similar forest conditions (figure 1). At the same time, at least 100 trees were examined at each object. Taxation indicators of plantations growing on the objects under study are given in Table 1.

![Figure 1. The layout of the objects under study.](image)

**Table 1.** Silvicultural and taxation characteristics of the research objects.

| Object No. | Plantation composition | Trunk diameter (1.3 m), cm | Height, m | Crown diameter, m | Age, years | Forest site type |
|------------|------------------------|-----------------------------|-----------|------------------|------------|-----------------|
| 1          | 4Mw4EBw1Bw1Hn          | 42                          | 15.8      | 5.5              | 50         | D2              |
| 2          | 5Cw3Bw1Mw1Ac           | 32                          | 11.3      | 4.0              | 45         | D2              |
| 3          | 4Mw2Cw2EBw2Hn          | 36                          | 14.2      | 5.0              | 45         | D2              |
| 4          | 4Bw4EBw2Cw             | 32                          | 12.6      | 4.5              | 40         | D2              |
| 5          | 8Mw2Mp+Ln              | 32                          | 11.4      | 4.0              | 35         | C2D             |
| 6          | 5Cw4Hn1EBw+Bw          | 34                          | 12.8      | 4.5              | 30         | D2              |
For introduced tree species, the most important indicators are the degree of adaptation of plants and their state. Evaluation of the state of plants growing in forest and forest-park zones was made visually, according to the Rules of sanitary safety in forests [12].

The degree of weakening (state) of the plantation was determined as the weighted average of estimates of the volumes' distribution of a tree trunk of different state categories. The criterion of viability is a complex of visual signs (thickness and color of the crown, the presence and proportion of dried out branches, etc.) of the living part of the plant [12].

If the value of the weighted average did not exceed 1.5, then the plantation was referred to healthy ones, 2.5 – to weakened, 3.5 – strongly weakened, 4.5 – to dying.

The value of the weighted average was calculated by the formula:

$$K_{av} = \frac{P_1 \times K_1 + P_2 \times K_2 + \ldots + P_n \times K_n}{100}$$

where $K_{av}$ – species weighted average; $P_i$ – the proportion of trees in each category of state as a percentage of the total stock; $K_i$ – category index of the tree state (1 – without signs of weakening, 2 – weakened, 3 – strongly weakened, 4 – drying, 5 – fresh deadwood, 6 – old deadwood, windfall, windbreak, 7 – emergency trees).

When assessing the fruit quality, the “Program and methodology of selection of walnut” proposed by Yu. I. Sukhorukikh et al. was taken as a basis [13]. The fruits were used in a dry state (humidity not more than 15%). The sample size is at least 50 pieces.

The estimated scale proposed by the author was used (Tables 2-5) taking into account the species peculiarities of nuts and the morphogenesis characteristic of the region, with significant reliability of the differences between the average values of the determined features.

**Table 2.** Criteria and grades used in assessing the quality of different fruit of the genus *Juglans*.

| Assessed signs | Sign parameters by grades (1-5) |
|---------------|---------------------------------|
| Gustatory qualities, points | Very bad (fruit is completely inedible) | Bad (fruit is almost not suitable for eating in fresh condition) | Satisfactory (moderate) | Good (table) | Perfect (dessert) |
| Resistance of fruit to diseases and pests, % | Affected (affected > 40) | Weakly resistant (affected 26-40) | Medium resistant (affected from 11 to 25) | Highly resistant (not more than 10 are affected) | “Absolutely” resistant (no affection) |
| Kernel exit, % | Incomplete (voids make up > 30% of the kernel diameter) | Small (voids between the surface of the kernel and the shell make up from 21 to 30% of the kernel diameter) | Medium (there is a space from 11 to 20% of the kernel diameter) | Large (there is a void less than 10% of the kernel diameter between the surface of the core and the shell) | Full (the kernel is tightly adjacent to the shell) |
| Uniform size of nuts, % | Non-uniform (size differences > 40) | Weakly uniform (26-40) | Medium (nuts differ for 16-25) | Uniform (differences for 6-15) | Absolutely uniform (differences do not exceed 5) |
| Easiness of the kernel separation, | Poorly separated (the kernel is | Hardly separated (the kernel is | Medium separation (the kernel is | Easily separated (the kernel is | Perfectly separated (the kernel is |
points separated in very small parts, with difficulty) separated in parts, with difficulty) separated in parts with effort) separated in parts without effort) separated entirely without much effort)

Shell hardness, points

"Paper" (crack with a slight pressure of fingers) Deformable (crack with little effort) Medium hard Hard (effort is required, but it is possible to crack with fingers) Extremely hard (considerable effort is required to crack)

Average seam thickness, mm

Invisible (less than 1) Smooth (1.1-3.0) Medium (3.1-5.0) Thickened (5.1-7.0) Extremely thickened (>7)

Thickness and structure of partitions, points

Very thin (fragile partitions, without woody inserts) Thin (partitions with woody inserts) Medium (partitions having a structure similar to the shell in 50% of cases) Thick (partitions not differing from the shell either in structure or in thickness) Very thick (partitions having a structure and thickness comparable to the shell thickness)

The nature of the surface and the color of the shell, points *

With very well developed ribs Knobby and ribbed (at the same time) Knobby or ribbed Dark and smooth Light and smooth (ribs are barely noticeable)

*The color and nature of the shell surface largely determine the marketable appearance of fruit, so it is advisable to consider them together with each other – the lighter and smoother the surface of the shell, the more attractive the appearance of fruit.

Table 3. Criteria and grades used in assessing the quality of Manchurian walnut.

| Assessed signs                  | Sign parameters by grades (1-5) |
|---------------------------------|----------------------------------|
| Fruit (endocarp) weight, g      | 1                                |
| Very light (less than 4.0)      | Light (4.1-5.5)                  |
| Light (4.1-5.5)                 | Medium (5.6-7.0)                 |
| Medium (5.6-7.0)                | Heavy (7.1-8.5)                  |
| Extremely heavy (more than 8.5)|                                  |
| Nut sizes, cm                   | 2                                |
| Very small (edge or length sizes are less than 1.5) | Small (1.5-2.3) |
| Small (1.5-2.3)                 | Medium (2.4-3.2)                 |
| Medium (2.4-3.2)                | Large (3.3-4.0)                  |
| Large (3.3-4.0)                 | Extremely large (more than 4.0) |
| Shell thickness, mm             | 3                                |
| Very thin (1.0 and thinner)     | Thin (1.1-2.2)                   |
| Thin (1.1-2.2)                  | Medium (2.3-3.4)                 |
| Medium (2.3-3.4)                | Thick (3.5-4.6)                  |
| Thick (3.5-4.6)                 | Extremely thick (4.7 and more)   |
| Kernel exit, %                  | 4                                |
| Very low (less than 12)         | Low (12-14)                      |
| Low (12-14)                     | Medium (15-17)                   |
| Medium (15-17)                  | High (18-20)                     |
| High (18-20)                    | Extremely high (21 and more)     |

To assess the quality of grey walnut, a similar scale is used with the changes that relate only to the endocarp weight and sizes:

– By weight, nuts are divided into very light – less than 10 g, light – 10.1-15.0 g, medium – 15.1-20.0 g, heavy – 20.1-25.0 g, and very heavy – more 25.0 g;
Depending on the nut sizes, they are divided into – very small (sizes on the ribs less than 4.0 cm), small (4.1-6.0 cm), medium (6.1-8.0 cm), large (8.1-10.0 cm) and very large (the dimensions on the ribs exceed 10.0 cm).

Table 4. Criteria and grades used in assessing the quality of black walnut.

| Assessed signs       | Sign parameters by grades (1-5)       |
|---------------------|---------------------------------------|
| Fruit (endocarp)    |                                       |
| weight, g           | Very light (less than 6.0)            |
|                     | Light (6.1-9.0)                        |
|                     | Medium (9.1-12.0)                      |
|                     | Heavy (12.1-15.0)                      |
|                     | Extremely heavy (more than 15)        |
| Nut sizes, cm       | Very small (edge or length sizes are  |
|                     | less than 2.0)                         |
|                     | Small (2.0-3.1)                        |
|                     | Medium (3.2-4.3)                       |
|                     | Large (4.4-5.5)                        |
|                     | Extremely large (more than 5.5)       |
| Shell thickness, mm | Very thin (1.0 and thinner)           |
|                     | Thin (1.1-2.0)                         |
|                     | Medium (2.1-3.0)                       |
|                     | Thick (3.1-4.0)                        |
|                     | Extremely thick (4.1 and more)        |
| Kernel exit, %      | Very low (less than 14)               |
|                     | Low (15-17)                           |
|                     | Medium (18-20)                        |
|                     | High (21-23)                          |
|                     | Extremely high (24 and more)          |

Table 5. Criteria and grades used in assessing the quality of heartnut.

| Assessed signs       | Sign parameters by grades (1-5)       |
|---------------------|---------------------------------------|
| Fruit (endocarp)    |                                       |
| weight, g           | Very light (less than 3.5)            |
|                     | Light (3.5-5.0)                        |
|                     | Medium (5.1-6.5)                       |
|                     | heavy (6.6-8.0)                        |
|                     | Extremely heavy (more than 8)         |
| Nut sizes, cm       | Very small (edge or length sizes are  |
|                     | less than 1.5)                         |
|                     | Small (1.5-2.1)                        |
|                     | Medium (2.2-2.8)                       |
|                     | large (2.9-3.5)                        |
|                     | Extremely large (more than 3.5)       |
| Shell thickness, mm | Very thin (0.8 and thinner)           |
|                     | Thin (0.9-1.2)                         |
|                     | Medium (1.3-1.6)                       |
|                     | thick (1.7-2.0)                        |
|                     | Extremely thick (2.1 and more)        |
| Kernel exit, %      | Very low (less than 21)               |
|                     | Low (21-25)                           |
|                     | Medium (26-30)                        |
|                     | high (31-35)                          |
|                     | Extremely high (36 and more)          |

The recommendations by B A Dospekhov were taken into account when planning the required sample size and performing statistical processing of the data obtained [14].

3. Results and discussion

The sanitary condition of plantings is a qualitative characteristic determined by the ratio of trees of different categories of state. Table 6 shows the averaged indicators of the sanitary state of plants of the studied Juglans species.

From the data given in the table, it follows that the best condition of the plants of the genus Juglans is marked in black walnut – 2.19 points. In optimal conditions, black walnut has excellent growth and condition [7,9]. Manchurian, heartnut and grey walnuts plantings have an average state score of 2.32-2.45, with insignificant differences between average values. Therefore, it can be concluded that the plantations are relatively homogeneous. Therefore, it can be concluded that the species of the genus Juglans are relatively homogeneous condition.
Table 6. Statistical indicators of the sanitary state of the *Juglans* plantations in the Voronezh region

| Types of nuts of the genus *Juglans* | Statistical indicators | Differences between average values |
|-------------------------------------|------------------------|-----------------------------------|
|                                     | M±m, points            | C, %                              | P     | t     | M1  | M2  | M3  | t0.05 |
| *J. nigra*                          | 2.19±0.096             | 43.96                             | 4.38  | 22.81 | -   | -   | -   | 1.96  |
| *J. manchurica*                     | 2.32±0.074             | 36.81                             | 3.19  | 31.35 | 0.96| -   | -   | 1.96  |
| *J. cinerea*                        | 2.45±0.109             | 38.52                             | 4.45  | 22.48 | 2.16| 1.01| -   | 1.96  |
| *J. cordiformis*                    | 2.37±0.091             | 41.10                             | 3.84  | 26.04 | 1.37| 0.32| 0.62| 1.96  |

where: *M* – mean value of the feature, *m* – error of the mean value, *C* – coefficient of variation, *P* – possible error in the study, *t* – reliability of the study, *t* (*M*) – validity of differences, *t0.05* – Student's test.

Weakened plantations prevailed at all the sites. The degree of weakening is due to lack of care and competition with fast-growing tree species. To ensure viable plantations, it is necessary to grow nuts in a free-growing environment.

Statistical results for the studied species of the genus *Juglans* on the total number of trees growing on all the objects have sufficient levels of accuracy (*P* < 5) and confidence (*t*). The ratio of the total volume of tree trunks by the categories of state (%) is shown in figure 2.

![Figure 2. Distribution of types of the *Juglans* species by categories of state in the studied plantations.](image)

Particular attention should be paid to the quality of fruit. Fruit should have a rather large kernel, high yield and good separation of the kernel, a pleasant taste. In addition, the nuts should have non-thick and not overgrown shells, and, if possible, an attractive appearance. The significance of these
assessment criteria is noted in the works by leading experts [4,13]. The “bunches arrangement” of fruit is also desirable, since this increases not only the yield, but also aesthetic evaluation of the trees.

Considering the widespread variety of forms of the genus \textit{Juglans} in the Voronezh region (when a new form can be often found in a separate tree), it is important to use a modernized graded scale (Table 7). Each of the indicators plays a certain role in the overall assessment of fruit quality, and its degree of significance varies depending on the species and purpose. The higher their total indicators, the more valuable the types or forms. In an overall assessment of fruit quality, the values of the evaluation criteria (EC) are summarized, such as: gustatory qualities, size, uniformness and weight of fruit, ease of separation, completion and yield of the kernel, surface character and shell color; values of hardness and thickness of the shell, thickness of the seam and partitions. The levels of significance of the main evaluation criteria for the quality of nuts are shown in figure 3.

![Figure 3](image_url)

**Figure 3.** The levels of significance (F) of the main evaluation criteria for the quality of nuts: 1 – shell thickness; 2 – shell hardness; 3 – weight of fruit; 4 – plumpness of the kernel; 5 – kernel exit; 6 – easiness of kernel separation; 7 – gustatory qualities.

**Table 7.** The grading distribution of qualitative signs of fruit belonging to the genus \textit{Juglans}

| Assessed sign | Grading, % |
|---------------|------------|
|               | 1 | 2 | 3 | 4 | 5 | K |
| Manchurian walnut | 4 | 12 | 63 | 21 | - | 7 |
| Eastern black walnut | 3 | 10 | 42 | 29 | 6 | 4 |
| White walnut | 5 | 2 | 4 | 23 | 5 | 8 |
| Heartnut | 7 | 20 | 32 | 58 | 21 | - |
| Kernel exit | 6 | 5 | 39 | 21 | 4 | 7 |
| Gustatory qualities | 7 | 20 | 32 | 58 | 21 | - |
| Nut size | 9 | 24 | 37 | 32 | 26 | 4 |
| Nut weight | 10 | 25 | 34 | 26 | 4 | 3 |
| Easiness of kernel separation | 11 | 49 | 33 | 7 | 6 | 3 |
| Kernel plumpness | 12 | 53 | 35 | 12 | 2 | 5 |
| The nature of the surface and the color of the shell | 13 | 9 | 21 | 44 | 26 | 3 |
| Uniform size of nuts | 14 | 5 | 5 | 43 | 53 | 6 |
| Shell hardness | 15 | 38 | 51 | 5 | 8 | 4 |
| Shell thickness | 16 | 34 | 55 | 85 | 7 | 8 |
| Seam thickness | 17 | 34 | 55 | 85 | 7 | 8 |
| Partition thickness | 18 | 56 | 39 | 56 | 2 | 5|
More than 15% of highlighted forms and individuals of the studied species black walnut and heartnut, as well as about 6% forms of Manchurian walnut, have perfect gustatory qualities. At the same time, all of them are eatable, and therefore are recommended for mass cultivation. No fruit with excellent taste was found among the studied forms of grey walnut. Individuals with excellent easiness of kernel separation have been identified in the *Juglans cordiformis*. The correlation coefficients of fruit quality and the main criteria for their assessment are shown in figure 4.

![Figure 4](image-url). The correlation coefficients of fruit quality: 1 – kernel exit; 2 – shell hardness; 3 – gustatory qualities; 4 – plumpness of the kernel; 5 – easiness of kernel separation; 6 – weight of fruit; 7 – shell thickness.

A high level of correlation (0.74-0.87) was found between the quality of the fruits of the species of nuts of the genus *Juglans* and their taste. A close correlation between the quality of the fruits was noted with ease of isolation of the kernel from the shell (0.5-0.67) and the kernel exit (0.24-0.59).

The significance of the evaluation quality criterion of fruit (EC) is calculated as a weighted average arithmetic value (point), taking into account the specific weight of each grade and is expressed by the following formula:

$$EC = \frac{c_1 \times n_1 + c_2 \times n_2 + \ldots + c_5 \times n_5}{100}$$

where $c$ – the coefficient given for each evaluation criterion; 1-5 – evaluated grades according to the proposed method; $n_1$-$n_5$ – a number of fruits of appropriate grade, %.

The higher their total indicators are, the more the form matters. In the general assessment of the quality of the fruit (score), the values of the evaluation criteria (EC) are summarized taking into account the sign of the species coefficient. The specific value for the cultivation as a fruit crop is shown when calculating the weighted average of the fruit quality of the genus *Juglans* (point). The average quality values of different nuts ($M \pm m$) are as follows: heartnut equal to 188.1±3.77; black walnut equal to 135.7±3.49; Manchurian walnut equal to 114.5±3.18; grey walnut equal to 87.2±1.86. The form is of potential interest for cultivation and selection when the obtained value of EC is above the average.

### 4. Conclusion

Manchurian walnut and grey walnut show the greatest vitality (average grade of sanitary condition is 2.19). The rest of the studied species of the genus *Juglans* also fall into the “weakened” category, and they are recommended for the creation of forest crops and landscaping in the Voronezh region. Grey walnut and heartnuts, as a rule, show the earliest drying of branches, in comparison with black walnut.
Talking about the quality of the fruit (points), the studied types of nuts can be arranged in the following order: heartnut equal to 188; black walnut equal to 136; Manchuria walnut equal to 115; grey walnut equal to 87. The black and heartnuts have the best combination of fruit condition and quality. Moreover, these tree species exhibit the most comprehensive resistance in terms of adaptive characteristics [15], and, therefore, are primarily recommended for full reforestation and afforestation in the Voronezh region.

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