Research article Open Access

BCHD
Bioactive Compounds in Health and Disease

The change in functional components in mulberry fruits (Morus alba L.) through the development of an optimal land transformation scheme for different land types

Inga Beglaryan[1], Gayane Gasparyan*[1], Stepan Khachatryan[2], Seryoja Yeritsyan[1], Arevik Eloyan[1], Tatevik Jhangiryan[1]

[1]Hrant Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration, Branch of Armenian National Agrarian University (ANAU) Foundation, 24 Isakov Ave., Yerevan 0004, Armenia; [2]Armenian National Agrarian University (ANAU) Foundation, Armenia, Teryan St., 74 Building, Yerevan, 0009, Armenia

***-Corresponding Authors:** Gayane Gasparyan - Hrant Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration Branch of Armenian National Agrarian University (ANAU) Foundation, 24 Isakov Ave., Yerevan 0004, RA.

Submission Date: February 25th, 2025, **Acceptance Date:** March 20th, **Publication Date:** March 28th, 2025

Please cite this article as: Beglaryan I., Gasparyan G., Khachatryan S., Yeritsyan S., Eloyan A., Jhangiryan T. The change in functional components in mulberry fruits (Morus alba L.) through the development of an optimal land transformation scheme for different land types. *Bioactive Compounds in Health and Disease* 2025; 8(3): 113 - 129.
DOI: https://www.doi.org/10.31989/bchd.8i3.1583

ABSTRACT

Background: Transforming agricultural land types using optimal economic-mathematical modeling can significantly improve soil quality, leading to better crop yield and quality. These changes are particularly important for promoting the production of functional foods, which provide additional health benefits beyond basic nutrition. Mulberry cultivation in brown soils is a key example, as it is a rich source of functional food, known for its high nutritional value and positive health effects. Mulberries have been used in traditional Armenian folk medicine for centuries, and their inclusion in functional food production further highlights their nutritional and health-promoting benefits.

Objective: This study, conducted from 2020 to 2024 in two communities in the Syunik region of Armenia, aimed to explore the impact of agricultural land transformation by applying an optimal economic-mathematical model on brown soils. The study focused on improving qualitative indicators of agricultural land types to promote higher productivity and functional effectiveness of mulberry cultivation.

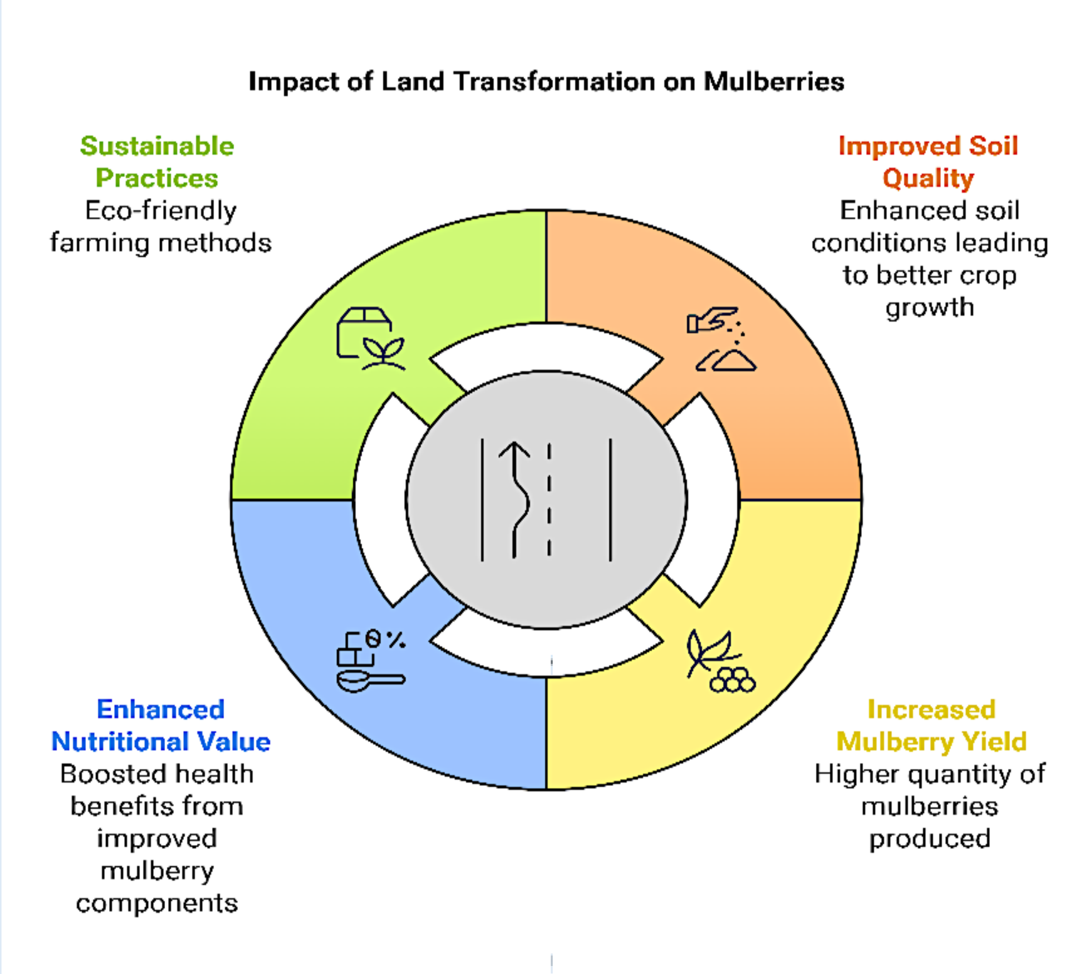
Methods: The study utilized an economic-mathematical model to enhance the qualitative indicators of agricultural land, achieving economic, social, and environmental benefits. The focus was on land transformation strategies that would increase the functional effectiveness of mulberries and boost their cultivation in different land types.

Results: Land transformation through applying optimal economic-mathematical modeling enhanced soil quality, directly improving the yield and quality of mulberry crops. The optimized land conversion strategies resulted in significant improvements in the functional components of mulberries, boosting their nutritional value and health benefits (Rutin (Quercetin 3-O-rutinoside)-71.1±4.8 mg/100g, Isoquercitrin (Quercetin 3-O-glucoside)-11.0±0.3 mg/100g, Malonyl flavonoids (Quercetin 3-O-(6´´-O-malonyl) glucoside and Kaempferol 3-O-(6´´-O-malonyl) glucoside) are also present in significant amounts, suggesting the potential for additional beneficial properties). Additionally, the increased efficiency of mulberry cultivation under transformed soil conditions highlights the potential for sustainable agricultural practices. The results confirm that such agricultural innovations increase productivity and better environmental outcomes. Land transformation by applying optimal economic-mathematical modeling enhances soil quality, directly improving the yield and quality of mulberry crops. The optimized land conversion strategies resulted in significant improvements in the functional components of mulberries, boosting their nutritional value and health benefits. Additionally, the increased efficiency of mulberry cultivation under transformed soil conditions highlights the potential for sustainable agricultural practices. The results confirm that such agricultural innovations lead to increased productivity, better environmental outcomes, and the improvement of the qualitative characteristics of functional food products.

Novelty: This study is the first to investigate the chemical changes in large and sweet white mulberries through optimal economic-mathematical modeling and land transformation schemes. It explores how changes in land quality indicators contribute to economic, social, and environmental benefits, ultimately advancing the production of health-promoting foods.

Conclusion: The study highlights the significance of applying optimal economic-mathematical modeling to transform agricultural land types. The results show that land transformation improves soil quality and crop yield while enhancing mulberry cultivation's functional effectiveness. These transformations contribute to promoting sustainable agricultural practices and supporting the production of functional foods.

Keywords: land transformation, digital matrix, Solver project, mulberry, functional components, effectiveness.



Graphical abstract: Impact of Land Transformation on Mulberries

INTRODUCTION

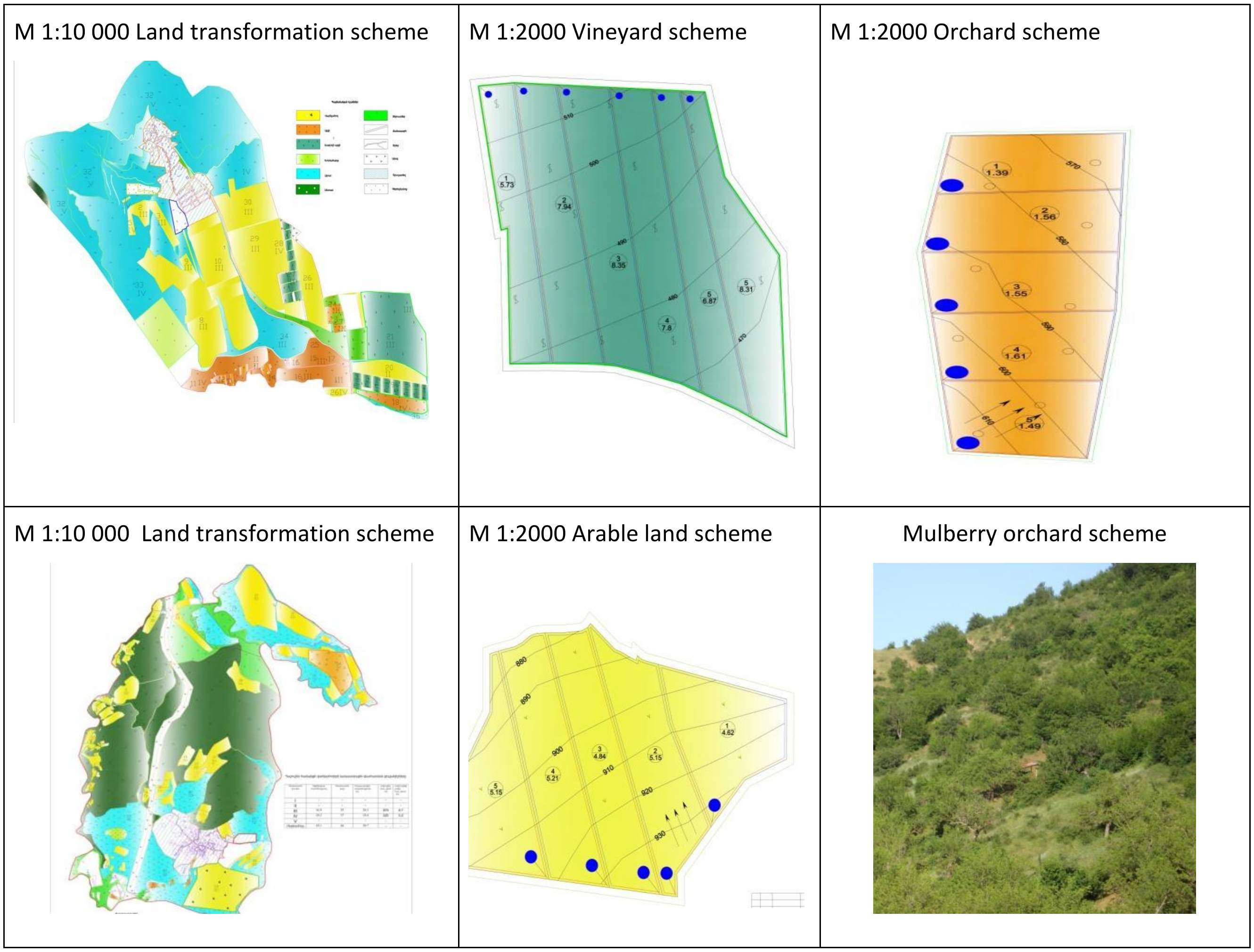
To address issues related to the efficient use and organization of agricultural land, it is essential to apply the latest technologies that contribute to creating a sustainable land resource management system, making the efficient use of land a reality [1-2]. Agricultural production constantly evolves globally, with current efforts focused on solutions that support environmental conservation by improving how we manage land. The goal is to increase crop productivity and enhance its health benefits, functionality, and sustainability while considering geographical and regional specificities [3-4].

Concurrently, land-use transformations impact plants' functional components, depending on the soil's accumulated nutrients and the applied agrotechnical practices [5-6]. Recent interest in healthy food has increased focus on edible plants' functional benefits [7]. The functional components of mulberry (Morus alba L.), originally cultivated for sericulture, have been assessed in several studies [89]. These plants offer significant health benefits due to their functional components, such as antioxidants, vitamins, and minerals, contributing to human well-being and disease prevention. The growing awareness of functional foods has spurred research into efficient cultivation methods to enhance both traditional and nutritional uses, supporting healthier and more sustainable diets [10, 11, 12]. Functional foods offer additional health benefits beyond basic nutrition and are crucial in modern agricultural practices, addressing challenges like food security, malnutrition, and chronic diseases [13-17].

Mulberry (*Morus spp*.) is a versatile and valuable plant with numerous beneficial properties for the sericulture industry and the food, pharmaceutical, and environmental sectors. Different parts of the mulberry plant are utilized for various purposes, from using mulberry leaves in supplements to enhance protein content, to extracting bioactive compounds for phytotherapy. Mulberry thrives in temperate to tropical climates and has been significant in sericulture and Ayurveda for centuries [18]. Known for their biologically active compounds, minerals, and flavanols [19, 20], mulberry fruits' nutritional and functional components are influenced by soil chemistry, cultivar, cultivation techniques, harvest time, and fruit maturity. [20-22]. Over 15 species and 500 varieties exist, with *M. alba*, *M. indica*, and *M. nigra* being crucial for leaf and fruit production. The leaves are primarily used for silkworm feeding, while in Europe, the fruit is used to produce jams, vinegar, wine, and pastries. Mulberry leaves and fruits are abundant in bioactive compounds such as rutin, quercetin, kaempferol, gallic acid, and chlorogenic acid, which have antioxidative, anti-inflammatory, and cardioprotective effects [23-24]. Mulberry fruits also contain 1-Deoxynojirimycin (DNJ), a polyhydroxy alkaloid with significant medicinal applications. Studies show that mulberry leaf powder can improve symptoms in cardiovascular patients and positively affect type 2 diabetes model rats [23-25], leading to growing interest in mulberry cultivation worldwide.

Mulberries can be cultivated in a wide range of soils and conditions unsuitable for most crops. However, they thrive best in temperatures ranging from 13 °C to 37.7 °C, with optimal bud sprouting occurring between 24 °C and 28 °C, and a relative humidity of 65-80%. They require 5 to 12 hours of sunlight daily and can grow in areas with rainfall ranging from 600 mm to 2500 mm, although irrigation may be necessary in drier areas [26]. Mulberries prefer slightly acidic to neutral sandy loam soils (pH 6.2–6.8) rich in organic carbon. Cultivation requires regular irrigation, fertilization, and pest control. The overuse of pesticides can compromise the quality of leaves and fruits, which are used in sericulture and other applications. Mulberry trees have self-healing abilities and do not need additional fertilization or pest treatments, making them ecologically clean. The fruit is rich in sugars, acids, and vitamin C and is used fresh, dried, or processed into products like molasses, jams, and spirits. In medicine, various plant parts treat conditions like diabetes, gastrointestinal disorders, dehydration, and cardiovascular diseases [23-26].

This study is the first to explore the chemical changes in large and sweet white mulberry fruits grown on transformed lands using optimal economic-mathematical modeling, with the creation of an optimal land transformation scheme. The study also analyzes the changes in the qualitative indicators of agricultural land, which bring economic, social, and environmental benefits. The article presents the chemical composition changes of large and sweet white mulberry fruits grown on transformed lands using optimal economic-mathematical modeling, focusing on the Syunik region of Armenia.



Graphical scheme: Optimal Scheme for Land Transformation**:** The graphical scheme presents the land planning layouts of two communities studied using AutoCAD software, on which the areas of transformed plots are outlined. Then, the transformed plots of vineyards, fruit orchards, and arable lands are separately designed, and in the final image, the existing Mulberry orchard is shown.

MATERIALS AND METHODS

The research was conducted in two typical communities of the Syunik region of Armenia (Vardanidzor, Tkhkut – which face similar challenges in improving the efficiency of agricultural lands) between 2020 and 2024, using the optimal scheme of economic-mathematical modeling for land transformation in brown soils, aiming to study the functional efficiency of mulberry fruits as a result of the improvement of land quality indicators. The chemical changes of large and sweet white mulberries and the increase in productivity in brown soils were also examined.

One of the main challenges in land management is developing efficient schemes for transforming agricultural land types, which allows for a transition from the current land use structure to a more effective land use system. To develop the economic-mathematical model, let Xij represent the area of the i-th plot of land that is transformed into j-th plot, considering different types of land. The system of constraints will be as follows [27-30] .

A constraint based on the availability of land suitable for transformation:

$$\sum_{j} x_{ij} \leq P_i \quad i \in M_1$$

A constraint based on the financial expenditure required for the transformation:

$$\sum_{j} a_{ij} x_{ij} \leq A_i \quad i \in M_2$$

A constraint based on the use of machinery and mechanisms (capacity of both in-house and contracted construction organizations) :

$$\sum_{j} l_{ij} x_{ij} \leq L_i \quad i \in M_4$$

A constraint based on the use of fertilizers.

$$\sum_{j} w_{ij} x_{ij} \leq W_i \quad i \in M_5$$

A constraint based on the efficient use of labor resources:

$$\sum_{j} t_{ij} x_{ij} \leq T_i \quad i \in M_3$$

A constraint based in the use of irrigation water (community irrigation):

$$\sum_{j} h_{ij} x_{ij} \leq H_i \quad i \in M_7$$

A constraint based on the capital investment costs for transformation:

$$\sum_{j} d_{ij} x_{ij} \leq D_i \quad i \in M_8$$

A constraint based on the use of treatment materials:

$$\sum_{j} k_{ij} x_{ij} \leq K_i \quad i \in M_6$$

A constraint based on the effectiveness of capital investments.

The payback period for capital investments (Tt) is determined by the following formula:

$$T^t = \frac{\sum_{ij} d_{ij} x_{ij}}{\sum_{ij} q_{ij} x_{ij}}$$

The non-negativity condition for the variables can be expressed as the objective function takes the following form:

$$Z = \sum_{ij} c_{ij} x_{ij} \rightarrow \max$$

The net income can be determined using the following formula

$$q_i = B_i - Ç_j, \; q_i = B_j - Ç_i.$$

The mineral content, comprising nine inorganic elements, was determined using the protocols established by the Association of Official Analytical Chemists (AOAC). The analysis was conducted with an inductively coupled plasma optical emission spectrometer. The proximate analysis results were calculated on a 100 g basis of the fruit. Additionally, the amount of fruit produced per tree (kg/fresh mulberry) and the weight of each individual fruit were recorded. Sugar concentration was measured using a saccharometer. All results are the mean ± standard deviation from three independent trials [31-33].

Flavonoid Content Extraction and Analysis: Flavonoid extraction followed a modified standard procedure. A 1 g sample of powdered fruit was combined with 10 mL of an acidified hydro-alcoholic solvent (methanol:water: formic acid in a 50:45:5 v/v/v ratio), with 100 ppm galangin as the internal standard. The mixture was shaken for 5 minutes at 200 rpm, then centrifuged for 15 minutes at 3,000 rpm and 10°C. The supernatant was filtered using a 0.45 µm PTFE syringe filter, and 0.5 mL of the filtrate was diluted with water to a final volume of 5 mL. Solid-phase extraction (SPE) was used for purification, employing Sep-Pak C-18 cartridges. The cartridges were conditioned by washing with methanol and water, and the extract was applied to the cartridge. Impurities were removed with water, while flavonoid compounds were eluted with methanol. The concentrated extract was evaporated under nitrogen and redissolved in 0.5 mL of the original extraction solvent, without the internal standard, for instrumental analysis [31-34].

Flavonoid analysis was performed using Ultra-Performance Liquid Chromatography (UPLC) with a photodiode array detector (set at 280 and 320 nm) and a quadrupole time-of-flight mass spectrometer. UV spectra were collected within the 210–600 nm range. Chromatography was carried out on a Luna Omega 1.6 µm C18 column (150×2.1 mm, Phenomenex) at a column temperature of 30°C. The mobile phase consisted of 0.5% formic acid in water (A) and acetonitrile (B). The flow rate was maintained at 0.3 mL/min, with an injection volume of 5 µL. The gradient elution profile was as follows: 0–2 minutes, 7% B; 24 minutes, 15% B; 40 minutes, 30% B; 48-50 minutes, 60% B; 53–54 minutes, 90% B; 55-60 minutes, 7% B. Data are presented as mean ± standard deviation from three independent experiments [31-35].

RESULTS AND DISCUSSION

The transformation of agricultural land should be carried out based on the condition that the economic efficiency of the economy strives for its maximum potential (Table 1, 2) .

Table 1. Key variables in land transformation.

Land areas according to the project	Arable land, hectares	Fruit orchard, hectares	Vineyard, hectares	Mulberry Orchard	Grasss - land	Land suitable for transformation
Arable land	-	-	X_1	-	-	2
Grassland	X_2	-	-	X_3	-	2.5
Pasture	-	X_4	-	-	-	2.2
Other land plots	-	-	-	-	X_5	2.5

Table 2. Baseline data for the problem.

Land areas for land reclamation in the year	Intended use	Variables	Expenditures on the transformation					Yield, quintals per hectare		Unit production value, currency (AMD)		Production costs per hectare, currency (AMD)	
			Capital investments per hectare, in currency (AMD)	Labor costs per hectare, man-days	Machinery costs per hectare, machine-days	Mineral fertilizer usage per hectare, centner	Cost of treatment materials per hectare, currency	Before transformation	After transformation	Before transformation	After transformation	Before transformation	After transformation
Arable land	**Vineyard**	X_1	1200000	35	5.0	2.5	80000	250	230	7000	15000	1520000	1850000
Grassland	**Arable land**	X_2	550000	135.5	7.5	3.6	180000	30	280	4500	8500	50000	1200000
	Mulberry Orchard	X_3	400000	15.5	4.2	3.5	80000	30	90	4500	25000	50000	180000
Pasture	**Fruit orchard**	X_4	470000	15.8	3.0	2.7	98000	3	150	5000	12000	0	1052000
Other land plots	**Grassland**	X_5	350000	8.0	6.5	1.8	0	0	90	0	6500	0	120000

Table 3 . The expanded numerical matrix of the problem

	Variables					Type of constraints	Right-hand side of the constraints
	Arabel land (x1)	Fruit Orchard (x2)	Vineyard (x3)	Mulberry orchard (x4)	Grassland (x5)		
Values of the Variable	1,2	1,5	0,0	0,9	2,5	-	-
Arabel land,	0	0	1	0	0	≤	2
Grassland	1	0	0	1	0	≤	2,5
Pasture	0	1	0	0	0	≤	2,2
Other land plots	0	0	0	0	1	≤	2,5
Capital investments, currency (AMD)	1200000	550000	400000	470000	350000	≤	3500000
Labor costs, person-days	35	135,5	15,5	15,8	8	≤	280
Machine costs, machine-day	5,0	15,5	4,2	3,0	6,5	≤	50
Mineral fertilizer usage, centners	3	3,6	4	2,7	1,8	≤	18
Cost of treatment materials, currency (AMD)	80000	180000	80000	98000	0	≤	450000
Capital investment efficiency, currency (AMD)	-1226000	-1029000	-1937000	-676000	-423000	≤	0
Net income, currency	1600000	1180000	270000	748000	465000	→	Max

Table 4. . The results of the computational solution to the problems.

Variables					Grassland (x5)	Amount of unused resources	Type of constraints	The right-hand side of the constraints
	Arable land (x1)	Fruit Orchard (x2)	Vineyard (x3)	Mulberry orchard (x4)				
Values of the Variable	1,2	1,5	0,0	0,9	2,5	-	-	-
Arabel land	0	0	1	0	0	0	≤	2
Grassland	1	0	0	1	0	2,0	≤	2,5
Pasture	0	1	0	0	0	1,5	≤	2,2
Other land plots	0	0	0	0	1	2,5	≤	2,5
Capital investments, currency (AMD)	1200000	550000	400000	470000	350000	3500000	≤	3500000
Labor costs, person-days	35	135,5	15,5	15,8	8	280	≤	280
Machine costs, machine-day	5,0	15,5	4,2	3,0	6,5	48,2	≤	50
Mineral fertilizer usage, centners	3	3,6	4	2,7	1,8	15,2	≤	18
Cost of treatment materials, currency (AMD)	80000	180000	80000	98000	0	450000	≤	450000
Capital investment efficiency, currency (AMD)	-1226000	-1029000	-1937000	-676000	-423000	-4617183,915	≤	0
Net income, currency (AMD)	1600000	1180000	270000	748000	465000	5445526,346	→	Max

The expanded numerical matrix of the problem is presented in Table 3, while the results of the optimization solution are presented in Table 4. The problem is a linear programming problem, which was solved using an Excel program's Solver subroutine. Thus, in the Vardanidzor community of the Syunik region, it is necessary to transform 0.9 hectares of grassland into a mulberry orchard, 1.5 hectares of pasture into a fruit orchard, 2.5 hectares of other land types into grassland, and 1.2 hectares of grassland into arable land. The same problem has been solved identically for the Tkhkut community, where 2.5 hectares were converted into a mulberry orchard, 1.2 hectares of grassland were converted into arable land, 2.6 hectares of pasture were transformed into grassland, and 1.2 hectares of other land types were converted into arable land (table 4). The calculations were made using Armenian drams; the result is presented in dollars. As a result of the conversion, the Vardanidzor community will receive an income equivalent to 14,200 dollars in drams; in a similar solution to the problem, the Tkhkut community will receive an income equivalent to 15,900 dollars. The proposed method applies to any community, providing the opportunity to transition from the current land use structure to a more efficient land management system.

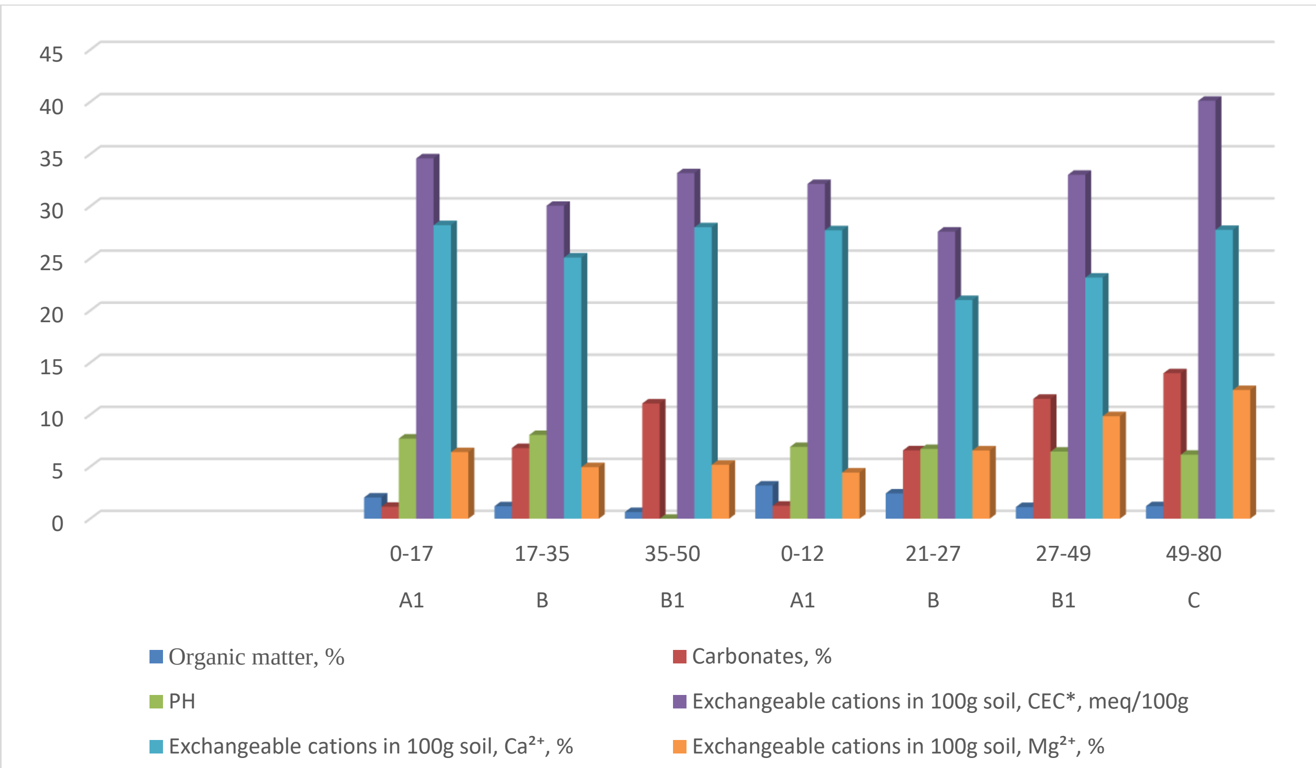


Figure 1: The chemical composition of brown soils. *Cation exchange capacity (CEC) is measured in milliequivalents per 100 grams of soil (meq/100g)

The chemical composition of brown soils varies across different horizons. Overall, the organic matter content decreases with depth, while the carbonate content increases.

- The soil data shows significant variation in physical and chemical properties across different soil horizons, which can influence plant growth.
- The **A1** horizon, with high organic matter and relatively neutral pH, is generally the most suitable

layer for planting due to its fertility and nutrient availability.

- The **B** and **B1** horizons, with higher alkalinity (pH 8.05) and carbonate content, might present challenges for some plants, as the alkaline conditions could limit nutrient availability.
- The **C** horizon, with the highest Exchangeable cations in 100 g soil CEC and rich in magnesium and calcium, indicates high potential for nutrient retention. Still, the relatively lower organic matter and neutral pH may require adjustments in plant selection. The variability in calcium and magnesium content across the horizons suggests the need for careful management of these nutrients to optimize plant growth at different depths.

In conclusion, the soil's physical and chemical properties, such as pH, CEC, and nutrient content (especially calcium and magnesium), vary across the depths, which should be considered when planning agricultural practices, as certain crops may thrive better in specific horizons depending on their nutritional requirements (Figure 1).

Table 5. The mulberry fruit amounts, weights, and sugar contents

Morus alba L.	Amount /kg/one tree/	Weights /g/one fresh fruit/	Sugar contents, %
	14.8±0.54	4.6±0.06	13.9±0.15

Each value represents the mean of three independent replicates ± standard deviation (SD).

The data show several important aspects of mulberry fruits' chemical composition, nutritional value, and flavonoid content. The number of mulberry fruits per tree is 14.8 ± 0.54 kg. The weight of one fresh fruit is 4.6 ± 0.06 g. The sugar content is 13.9 ± 0.15%, indicating that the fruits are rich in sugars. These values suggest that mulberry fruits contain a relatively high amount of sugar, which can be significant for health-conscious diets and managing conditions such as diabetes [39] since they provide natural sugars (Table 5).

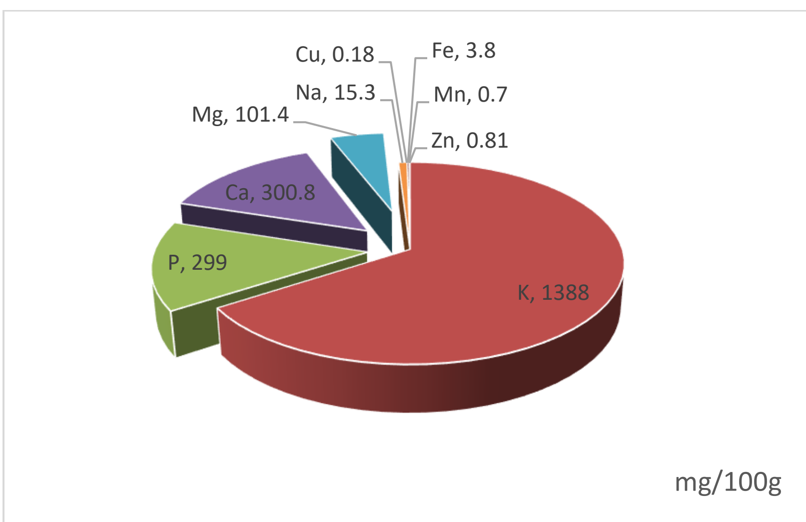


Figure 2: Mineral content of mulberry fruits. Each value represents the mean of three independent replicates ± standard deviation (SD).

Figure 2 presents the main micro and macro elements found in the fruits of Morus alba L. (mulberry) and their quantities per 100 g:

Potassium (K)—1388 mg—Potassium is essential for regulating blood pressure and the function of nerves and muscles. It is also a key element for maintaining fluid balance and energy production in the body. The high potassium content in mulberries can help people improve their cardiovascular health [36, 37].

Phosphorus (P) - 299 mg - Phosphorus is necessary in energy production and crucial for the strength of bones and teeth. It also supports muscle function. The high phosphorus level in mulberries contributes to overall metabolism and bone health [36, 37].

Calcium (Ca) - 300.8 mg - Calcium is essential for bone strength. It is also important for nerve communication and muscle function. The high calcium content in mulberries benefits bone health and overall body structure [36, 37].

Magnesium (Mg)—101.4 mg—Magnesium plays an important role in metabolic processes, especially muscle and nerve function. It helps regulate blood pressure. Magnesium in mulberries is also beneficial for relieving stress and anxiety [36, 37].

Sodium (Na) - 15.3 mg - Sodium helps maintain fluid balance in the body, but excessive amounts can raise blood pressure. Mulberries' relatively low sodium content contributes to maintaining healthy blood pressure levels [36, 37].

Copper (Cu) - 0.18 mg - Copper is important for combating oxidative stress and metal metabolism. It aids in the formation of hemoglobin in the blood. This mulberry element helps in cell regeneration and growth processes [37].

Iron (Fe) - 3.8 mg is crucial for blood production and oxygen transport. This element allows the body to use oxygen more effectively. Iron in mulberries helps prevent anemia and improves energy levels [36-37].

Manganese (Mn) - 0.7 mg - Manganese supports metabolic processes, particularly energy production, and acts as an antioxidant. The low levels of manganese may promote anti-inflammatory and antioxidant activity [37].

Zinc (Zn) - 0.81 mg - Zinc is important for the immune system, supporting cell regeneration and anti-inflammatory functions. It also promotes growth and recovery, and the high zinc content in mulberries supports overall health maintenance [36-37].

Table 6. The amounts (mg/100g dry weight) of nine flavonoids isolated from the mulberry fruit.

Individual Flavonols/Treatment	**Morus alba L. /mg/100g/**
Quercetin 3-O-rutinoside-7-O-glucoside (Morkotin A)	1.4±0.2
Quercetin 3,7-di-O-glucoside	0.4±0.1
Quercetin 3-O-rutinoside (Rutin)	71.1±4.8
Quercetin 3-O-glucoside (Isoquercitrin)	11.0±0.3
Quercetin 3-O-(6´´-O-malonyl) glucoside	26.7±2.2
Kaempferol 3-O-rutinoside (Nicotiflorin)	5.1±0.1
Kaempferol 3-O-glucoside (Astragalin)	3.0±0.1
Kaempferol 3-O-(6´´-O-malonyl) glucoside	3.9±0.3
Quercetin 3-O-(2´´-O-malonyl) glucoside (Morkotin C)	1.2±0.1

Each value is expressed as the mean ± standard deviation (SD) of three replicates, with galangin as the internal standard

(Table 6). Mulberry fruits are rich in various flavonoids known for their antioxidant and anti-inflammatory properties. The most prevalent flavonoid is Rutin (Quercetin 3-O-rutinoside), present at 71.1 ± 4.8 mg/100g. Isoquercitrin (Quercetin 3-O-glucoside) is found at 11.0 ± 0.3 mg/100g. Malonyl flavonoids, including Quercetin 3-O-(6´´-O-malonyl) glucoside and Kaempferol 3-O-(6´´-O-malonyl) glucoside, are also present in notable amounts, indicating their potential for additional health benefits [38-39]. The high flavonoid content of mulberry fruits highlights their health-promoting effects, which could aid in combating free radicals and protecting the body from various diseases (Table 6).

Due to their high sugar content and flavonoid presence, Mulberry fruits are nutritious and beneficial for health. These components are also crucial in processing industries, such as making syrup, jam, juice, and dried fruits. The study mentions that the data relates to brown soils, which contribute to the increased functional efficiency of mulberry fruits. This indicates that proper land management and transformation can enhance the quality of crops, positively influencing their characteristics due to the soil's nutrients and other properties.

Scientific Innovation and Practical Implications: This research presents a pioneering approach by integrating optimal economic-mathematical modeling with land transformation schemes to enhance the functional components of mulberry fruits. This novel methodology optimizes soil quality and directly impacts mulberries' nutritional profile, specifically targeting the increase of key functional compounds like Rutin, Isoquercitrin, and Malonyl flavonoids. By demonstrating significant improvements in mulberry cultivation through land transformation, this study establishes a new paradigm for enhancing the production of functional foods.

The practical implications of this research are substantial, offering a blueprint for sustainable agricultural practices that simultaneously improve crop yield, nutritional value, and environmental outcomes. The application of economic-mathematical modeling provides a replicable strategy for other agricultural regions to optimize land use and enhance the production of functional foods. Furthermore, identifying specific functional components in mulberries and the increased concentration through land transformation provides a valuable resource for developing new functional food products. This research advances our understanding of agricultural optimization and offers a practical pathway for enhancing food security and promoting healthier dietary options through innovative land management strategies."

CONCLUSION

The land transformation processes explored in this study demonstrate that optimizing soil quality significantly enhances the quality and productivity of mulberry crops. Moreover, these transformations improve the resulting products' functional properties, further boosting their health benefits. This underscores the potential of land transformation in increasing agricultural productivity and enhancing the functional value of crops like mulberries.

Abbreviations: UPLC: Ultra-Performance Liquid Chromatography, CEC: Cation Exchange Capacity, SPE: Solid-Phase Extraction, SD:: Standard Deviation.

Acknowledgments: The work was supported by the Base Financing of the Hrant Petrosyan Scientific Center of Soil Science, Agrochemistry and Melioration, Branch of Armenian National Agrarian University (ANAU) Foundation.

Author's Contribution: All authors contributed to this study.

Competing interests: The authors declare no conflict of interest.

REFERENCES

1. Walangitan, H. D., Setiawan B., Raharjo B. T. and Polii B. Optimization of Land Use and Allocation to Ensure Sustainable Agriculture in the Catchment Area of Lake Tondano, Minahasa, North Sulawesi, Indonesia, International Journal of Civil & Environmental Engineering IJCEE-IJENS 2012; 12(3), 68–75.
2. Xin Z., Dominique Y., Keeney R., Wallace T. Improving the way land use change is handled in economic models Economic Modelling 2020; 84, 13-26 DOI: https://doi.org/10.1016 /j.econmod.2019.03.003
3. Tegenie M., Ashebir S., Heliyon S. Potential of mathematical model-based decision making to promote sustainable performance of agriculture in developing countries: A review article 2022; 8 (2) DOI: https://doi.org/10.1016/j.heliyon.2022.e08968
4. Taratula R., Kovalyshyn O., Ryzhok Z., Malakhova S., 2019, Application of Mathematical Modeling for Optimization of Land-Use Management, Real Estate Management and Valuation, 2019(27),3: 59-68. DOI: https://doi.org/10.2478/remav-2019-0025
5. Shuhua Ma, Zhuzhu Wen. Optimization of land use straucture to balance economic benefits and ecosystem services under uncertainties: A case study in Wuhan, China, Journal of CleanerProduction 2021; 15 DOI: https://doi.org/10.1016/j.jclepro.2021.127537
6. Taratula R. , Kovalyshyn O. , Ryzhok Z. , Malakhova S. Application of Mathematical Modelling for Optimization of Land-Use Management. Real Estate Management and Valuation September 2019; 27(3):59-68 DOI: https://doi.org/10.2478/remav-2019-0025
7. Martirosyan, D. M., Stratton S. Comparing the FDA's process for health claim submission and the FFC's guidelines for regulating functional foods. Functional Foods in Health and Disease, 2023; 13(9): 424-436. DOI: https://www.doi.org/10.31989/ffhd.v13i9.1228
8. Wen P., Hu T.-G., Linhardt R.J., Liao S.-T., Wu H., Zou Y.-X. Mulberry: A review of bioactive compounds and advanced processing technology. Trends Food Sci. Technol. 2019, 83, 138–158. DOI: http://doi.org/10.1016/j.tifs.2018.11.017
9. Martirosyan, D., Lampert, T., and Lee, M. A comprehensive review on the role of food bioactive compounds in functional food science. Functional Food Science, 2022, 2(3), 64–79. DOI: https://doi.org/10.31989/ffs.v2i3.906
10. Martirosyan, D. M., Stratton S. Advancing functional food regulation. Bioactive Compounds in Health and Disease 2023; 6(7): 166–171. DOI: https://doi.org/10.31989/bchd.v6i7.1178
11. Martirosyan, D., Kanya, H. Nadalet, C. Can functional foods reduce the risk of disease? Advancement of functional food definition and steps to create functional food products. Functional Foods in Health and Disease 2021. 11(5), 213–221. DOI: https://doi.org/10.31989/ffhd.v11i5.788
12. Gasparyan G., Eloyan A., Jhangiryan T., Markosyan A., Beglaryan I., Barseghyan M. Wheat production management in saline soils using vinasse. Functional Food Science 2025; 5(1): 20–29. DOI: https://doi.org/10.31989/ffs.v5i1.1539
13. Jhangiryan T., Hunanyan S., Markosyan A., Yeritsyan S., Eloyan A., Barseghyan M., Gasparyan G. Assessing the effect of joint application of mineral fertilizers and biohumus on potato yield quality indicators. Functional Food Science 2024; 4(12): 508-520. DOI: https://www.doi.org/10.31989/ffs.v4i12.1528
14. Beglaryan I., Eloyan A., Daveyan S., Jhangiryan T., Yeritsyan S., Gasparyan G. Effectiveness of pumpkin cultivation in crop rotation on forest brown soil. Bioactive Compounds in Health and Disease 2025; 8(1): 1–10. DOI: https://doi.org/10.31989/bchd.8i1.1548
15. Jhangiryan T., Markosyan A., Yeritsyan H., Valeeva J., Petrosyan M., Valeeva G. Biohumus "Sis" for the ecologically pure agricultural production. BIO Web of Conferences 2022; (52):5. DOI: https://doi.org/10.1051/bioconf/2022520006
16. Larionov, M. V.., Sargsyan, K. S., Sayadyan, H. Y., Margaryan, V. GG. Hunanyan, S. A., Yeritsyan, S. K. et al. The Influence of

Cultivation, Storage and Processing Technology on the Nitrate Content in Potato Tubers and Vegetable Crops as an Example of Ecologically and Hygienically Oriented Organic Agricultural Nature Management. Journal of Ecohumanism, 2024. 3(8), 292–302.
DOI: https://doi.org/10.62754/joe.v3i8.4731

17. Jelled A., Ben R., Thouri A., Flamini G., Chahdoura H., Arem A., et. Immature mulberry fruits richness of promising constituents in contrast with mature ones: A comparative study among three Tunisian species Industrial Crops and Products 2017; 95, 434-443
DOI: https://doi.org/10.1016/j.indcrop.2016.10.053
18. Manzoor Shaista, and Kahkashan Qayoom. 2024. "Environmental Importance of Mulberry: A Review". Journal of Experimental Agriculture International 46 (8):95-105. DOI: https://doi.org/10.9734/jeai/2024/v46i82681
19. Gulab Khan Rohela, Pawan Shukla, Muttanna, Rajesh Kumar, Sukhen Roy Chowdhury, Mulberry (Morus spp.): An ideal plant for sustainable development, Trees, Forests and People, Volume 2, 2020, 100011, ISSN 2666-7193,
DOI: https://doi.org/10.1016/j.tfp.2020.100011.
20. Armachius J., Wang Ke, Ying Chen, Yousheng Wang. Food Bioscience Functional benefits of mulberry leaf tea or extracts to alleviate metabolic diseases: Current opinion and perspectives 2024; 59, DOI: https://doi.org/104218
21. Jan B., Parveen R.; Zahiruddin S.; Khan M.U.; Mohapatra S.; Ahmad S. Nutritional constituents of mulberry and their potential applications in food and pharmaceuticals: A review. Saudi J. Biol. Sci. 2021; 28, 3909–3921. http://www.ncbi.nlm.nih.gov/pubmed/34220247
22. Memete A.R., Timar A.V., Vuscan A.N., Miere F., Venter, A.C., Vicas S.I. Phytochemical Composition of Different Botanical Parts of Morus Species, Health Benefits and Application in Food Industry. Plants 2022; 11, 152. DOI: http://doi.org/10.3390/plants11020152
23. Wan-Taek Ju, Sora Lee, Heon-Woong Kim, You-Young Jo, Hae-Yong Kwon. Effect of the Nutritive Components of Mulberry Fruits from Two Cultivars Based on Irrigation Scheduling. Korean Journal of Environmental Agriculture 2020; 39 (4).352-359
DOI: https://doi.org/10.5338/KJEA.2020.39.4.42
24. Chen, C.; Mohamad Razali, U.H.; Saikim, F.H.; Mahyudin, A.; Mohd Noor, N.Q.I. Morus alba L. Plant: Bioactive Compounds and Potential as a Functional Food Ingredient. Foods 2021; 10, 689.
DOI: https://doi.org/10.3390/foods10030689
25. Park Ju-H., Hong Seok-In, Jeong Moon-Cheol. Quality characteristics and changes in mulberry (Morus alba L.) depending on their maturity during distribution, Korean Journal of Food Preservation 2013; 20(3),
DOI: https://doi.org/10.11002/kjfp.2013.20.3.304
26. Ritwik Acharya. Mulberry (Morus Spp): The Ultimate Plant For Sustainable Development, Futuristic Trends in Agriculture Engineering & Food Sciences Volume 3 Book 15, IIP Series, Volume 3, May 2024, Page no.726-738, e-ISBN: 978-93-5747-931-8,
DOI: https://www.doi.org/10.58532/V3BCAG15P6CH4
27. Volkov S.N. Land Management. Land Management Design. Internal Farm Land Management 2001; 2. 648 p. Kolos. (in Russian)
28. Volkov S.N. Land management. Economic and mathematical methods and models; 2001 Kolos. (in Russian)
29. Klimenko K., Melnichuk A., Popovich V. Geoinformation modeling of agricultural land transformation, BIO Web of Conferences 2024; 141, 02026
DOI: https://doi.org/10.1051/bioconf/202414102026
30. AOAC. (2007). Official Methods of Analysis (18th ed) Association of Official Analytical Chemist: Arlington, VA, USA.
31. Pawlowska M., Oleszek W., and Braca A. Qualiquantitative analyses of flavonoids of Morus nigra L. and Morus alba L. (Moraceae) fruits. Journal of Agricultural Food Chemistry 2008; 56. 3377–3380.
DOI: https://doi.org/10.1021/jf703709r
32. Ercisli S., and Orhan E. Chemical composition of white (Morus alba), red (Morus rubra) and black (Morus nigra) mulberry fruits. Food Chemistry 2007; 103. 1380–1384.
33. Zhang, J.; Chen, J.; Lan, J.; Liu, B.; Wang, X.; Zhang, S.; Zuo, Y. Effect of Different Drying Techniques on the Bioactive Compounds, Antioxidant Ability, Sensory and Volatile Flavor Compounds of Mulberry. *Foods* **2024**, *13*, 2492.
DOI: https://doi.org/10.3390/foods13162492
34. Wang, Y.; Jiang, W.; Li, C.; Wang, Z.; Lu, C.; Cheng, J.; Wei, S.; Yang, J.; Yang, Q. Integrated Transcriptomic and Metabolomic Analyses Elucidate the Mechanism of Flavonoid Biosynthesis in the Regulation of Mulberry Seed Germination under Salt Stress. BMC Plant Biol. 2024, 24, 132.

35. Witoyo, J. E., Utoro, P. A. R., Alvianto, D., & Naisali, H. (2024). An Overview of Extraction Methods of Bioactive Compounds from White Mulberry (Morus alba) Leaf. *Spizaetus: Jurnal Biologi Dan Pendidikan Biologi*, *5*(2), 319–335. DOI: https://doi.org/10.55241/spibio.v5i2.387
36. Othman AA, AMAO Aljabary, HJMDA Hama, FH Awlqadir, Evaluation of chemical, bioactive compounds and minerals of three mulberry species. Intl J Agric Biol 2024; 31:213–217 DOI: https://doi.org/10.17957/IJAB/15.2134
37. Ali Ali Redha, Afnan Freije, Chamali Kodikara, Mariangela Rondanelli , Eman Aqeel , Wajiha Zafar , etc. Comparison of fatty acid profile and mineral content of black mulberry (Morus nigra), white mulberry (Morus alba) and red mulberry (Morus rubra) grown in Bahrain. Applied Food Researc. 3 (2), 2023 DOI: https://doi.org/10.1016/j.afres.2023.100358
38. Sohail Z. (2023) Mulberry. Edible Berries-New Insights. Intech Open. Available at: DOI: http://dx.doi.org/10.5772/intechopen.1001887.
39. Memete A. R, Timar A. V, Vuscan A. N, Miere F, Venter A. C, Vicas S. I. Phytochemical Composition of Different Botanical Parts of Morus Species, Health Benefits and Application in Food Industry. Plants. 2022; 11(2):152. DOI: https://doi.org/10.3390/plants11020152