GROWTH PARAMETERS AND YIELD OF SIX APPLE CULTIVARS GROWN IN A HIGH DENSITY ORCHARD IN THE REPUBLIC OF MOLDOVA

Vasile Melnic[1], Orsolya Borsai[1], Viorel Mitre[2], Tincuța Marta Gocan[1], Claudiu-Ioan Bunea[1*]

[1]*Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Mănăștur St. 3-5, Cluj, Cluj-Napoca, Romania*

[2]*The Academy of Agricultural and Forestry Sciences "Gheorghe Ionescu-Şişeşti", Mărăști St., No. 61, Sector 1, Bucharest, Romania; *Corresponding author e-mail: claudiu.bunea@usamvcluj.ro*

Abstract. The main aim of this research was to investigate the growth parameters of six apple cultivars such as 'Reinette Simirenko', 'Golden Delicious', 'Idared', 'Generos', 'Champion' and 'Florina' and their yield grown in a high density orchard located in the Republic of Moldova. To determine the differences between the cultivars regarding their growth the trunk diameter, tree height, annual shoot growth, and canopy volume and trunk cross-sectional area were measured and calculated. To compare their yielding capacity, yield/ha and yield efficiency were recorded and calculated. The results showed that in terms of growth parameters the most vigurous cultivar was 'Golden Delicious' followed by 'Reinette Simirenko' with average trunk diameters of 119.23 and 119.13 mm. Tree height was also very similar between these two cultivars ranging between 2.69 and 2.83 m. However, the longest annual shoots were recorded in 'Generos' (33,53 cm) followed by 'Champion' (29.08). The lowest values in terms of growth parameters were recorded in 'Florina' and 'Generos'. Regarding yielding capacity, the most productive cultivars were 'Idared' and 'Champion' with yields of 40.48 and 40,23 tones/ha. The lowest yield was recorded in 'Florina'.

Keywords: annual shoot growth, trunk diameter, TCSA, yield efficiency, water deficit

INTRODUCTION

Apple cultivation plays a crucial role in global agriculture, providing not only a significant source of nutrition but also contributing to the economic stability of many regions (FAO, 2020). Apples are among the most widely consumed fruits globally and are appreciated for their exceptional nutritional and therapeutic properties. Rich in essential nutrients, apples are a valuable source of dietary fiber, vitamins (particularly vitamin C), and phytochemicals such as flavonoids and phenolic acids (Boyer & Liu, 2004). These compounds are associated with numerous health benefits, including antioxidant, anti-inflammatory, and cardioprotective effects.

Regular apple consumption has been linked to a reduced risk of chronic diseases, including cardiovascular disease, diabetes, and certain cancers (Hyson, 2011). The high fiber content, particularly in the form of pectin, contributes to improved gut health by promoting the growth of beneficial gut microbiota and enhancing digestion (Slavin, 2013). Additionally, the flavonoids in apples, such as quercetin, exhibit strong antioxidant activity, reducing oxidative stress and lowering the risk of neurodegenerative diseases like Alzheimer's and Parkinson's (Perez-Vizcaino & Duarte, 2010).

Therapeutically, apples also play a role in weight management and blood sugar regulation. Studies suggest that bioactive compounds in apples can modulate glucose metabolism and reduce insulin resistance, making them beneficial for individuals with or at risk of type 2 diabetes (Barreiro-Hurle et al., 2020). Furthermore, apple polyphenols have been shown to reduce LDL cholesterol levels, contributing to cardiovascular health (Bondonno et al., 2017).

However, climate change poses significant challenges to the sustainability of apple production. The effects of rising temperatures, unpredictable weather patterns, and altered pest dynamics are affecting apple cultivation worldwide.

Apples require a specific range of temperatures to maintain their growth cycle, particularly for processes like dormancy, flowering, and fruit development. Warmer winters, resulting in insufficient chilling hours, can disrupt bud development, delay flowering, and reduce fruit set (Atkinson et al., 2012). Additionally, increased temperatures during the growing season can lead to smaller fruit size and compromised quality due to accelerated respiration and reduced sugar accumulation (Fujisawa & Kobayashi, 2010).

Changes in precipitation patterns, including prolonged droughts and intense rainfall events, directly impact apple orchards. Water stress during critical growth stages reduces yield and fruit quality, while excessive rainfall can cause waterlogging, root diseases, and nutrient leaching (Chmielewski et al., 2018).

Climate change also influences the prevalence and severity of pests and diseases in apple orchards. Warmer temperatures and extended growing seasons favor the proliferation of pests like codling moths (*Cydia pomonella*) and aphids, increasing the risk of crop loss (Gregory et al., 2009). Similarly, diseases such as apple scab (*Venturia inaequalis*) may spread more rapidly in regions with increased humidity and rainfall (West et al., 2015).

Therefore, the main aim of this research was to investigate several apple cultivars in order to monitor their growth and yield under the climatic conditions of the Republic of Moldova and evaluate their potential to be used for future breeding programs.

MATERIALS AND METHODS

The current research has been carried out in a high-density orchard located in the Republic of Moldova in Jora de Mijloc (47°28′31″N; 29°05′36″E) at 15 m altitude above sea level during 2018-2020. The orchard has been established in 2009, with a planting distance of 1,5 x 4 m. All cultivars under study were grafted on M106 rootstock.

The plant material used for this experiment involved six apple cultivars such as ‘Reinette Simirenko’, ‘Golden Delicious’, ‘Idared’, ‘Generos’, ‘Champion’ and ‘Florina’ which were subjected to the same fertilization and pest and disease management practices.

To determine the differences in terms of growth parameters trunk diameter, trunk cross-sectional area, tree height, annual shoot growth, canopy volume were measured and calculated. The measurements and observations were carried out on 50 trees/variety. Trunk diameter was measured using a digital caliper while tree height and canopy spread with the use of a measuring tape. The yielding capacity of apple cultivars were determinde based on yield/ha. Yield efficiency has been calculated as a ratio between trunk diameter and yield/tree as described by Kumar et al. (2019).

The data collected were subjected to statistical analyses in order to determine significant differences between the cultivars. ANOVA test was performed to detect significant differences between the means, and when the null hypothesis was rejected, Tukey's HSD test was applied to determine significant differences between the means at the confidence level of $p<0.05$ and $n=50$.

RESULTS AND DISCUSSIONS

The success of an apple orchard higly depends on a combination of multiple factors including strategic planning, effective management, and environmental adaptability. Achieving high yields and quality fruit while maintaining sustainability requires careful attention to several key factors. However one of the most important factors lies in the selection of cultivars which are adapted or have an increased adaptability to local climate conditions (Robinson, 2004a; Atkinson et al., 2012b). The local annual average temperatures and rainfalls of the experimental site were collected from the World Bank Climate Data and presented in Tab. 1.

Tab. 1. Meteorological data of the experimental site during the three years of study

Experimental years	*Min. mean tem. (°C)*	*Max. mean temp. (°C)*	*Mean temp. (°C)*	*Precipitation (mm)*
2018	6.92	16.16	11.52	502.3
2019	7.62	17.22	12.39	376.53
2020	7.69	17.2	12.43	440.83

Source: World Bank Climate Data

The average annual temperatures recorded clearly showed an increasing trend across the three years of research. The rise of temperatures through the years entailed the decrease of average annual rainfall. The optimal range of average annual rainfall of apple trees are between 600–1,200 mm (Fereres and Goldhamer, 2003). This quantity of water can provide enough moisture for growth while avoiding waterlogging which might damage the root system. Despite the sub-optimal rainfall conditions, the apple trees were not irrigated during the experimental years. Therefore, the results reported here, indicate not only the tree growth parameters and yield of each cultivar but also the growth performance and yielding capacity of the cultivars under water stress conditions.

Among growth parameters, trunk diameter is one of the most critical parameter that should be considered in apple tree cultivation as it serves as an indicator of the tree's overall health, growth potential, and ability of yielding (Forshey and Elfving, 1989). Monitoring trunk diameter provides valuable insights for orchard management and plays a significant role in decision-making processes related to tree maintenance, pruning, and also spacing. The results regarding trunk diameter revealed that it value ranged between 108.30 and 119.23 mm among the six apple varieties under study (Fig. 1). The highest value was recorded for 'Golden Delicious' followed by 'Reinette

Simirenko'. The lowest value for this parameter was measured in 'Generos' cultivar (108.30 mm).

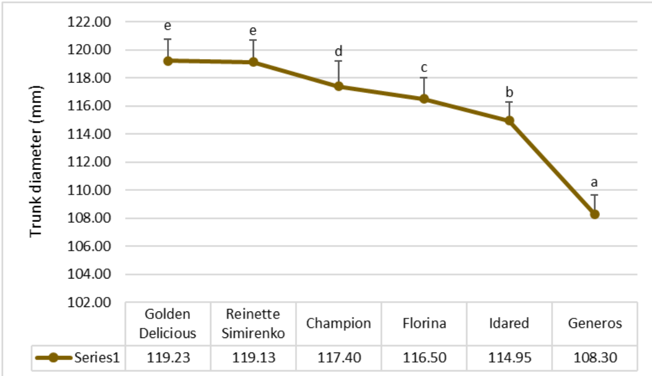

Fig. 1. Trunk diameter of the investigated apple cultivars. Different lowercase letters above the error bars indicate significant differences between the means at p<0.05

After the trunk diameter, the height of apple trees were measured. Tree height directly influences light interception, ease of management, and overall yield potential of the tree, making it an important factor in modern apple orchards (Jackson, 1980). Achieving the proper balance between tree height and management efficiency is essential. This can be achieved through careful rootstock selection, pruning practices, and canopy management strategies adapted to the specific needs of the orchard. The results of tree height measurements showed that the highest apple trees belonged to 'Golden Delicious' (2.83 m) followed by 'Reinette Simirenko' (2.69 m) as presented in Fig. 2. The lowest values for tree height were recorded in 'Champion' and 'Generos' with an average tree height of 2.55 and 2.27 m.

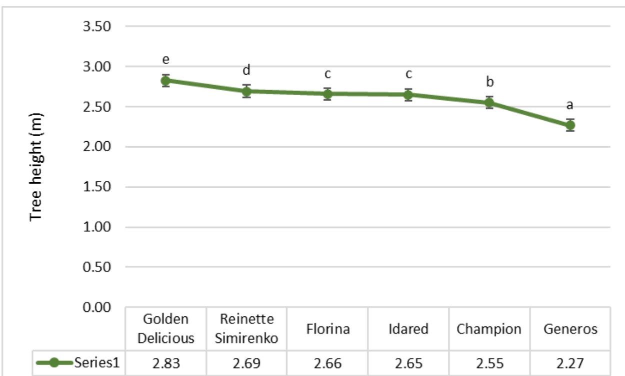

Fig. 2. Tree height of the investigated apple cultivars. Different lowercase letters above the error bars indicate significant differences between the means at p<0.05

The length of annual shoots indicate tree vigor. Excessive shoot growth can indicate over-fertilization or insufficient pruning, which may result in reduced fruit production due to competition between vegetative and reproductive growth (Robinson, 2004b). On the contrary, reduced shoot growth may indicate drought stress, nutrient deficiencies, or disease. Maintaining optimal shoot growth ensures balanced vegetative and reproductive development, supports efficient canopy structure, and promotes high-quality fruit production. By monitoring and managing shoot length, growers can enhance orchard productivity, sustainability, and economic returns. The result of annual shoot measurements revealed that shoot length varied significantly among the cultivars analyzed. The most vigurous cultivars from this point of view were ‘Generos’ with an average shoot growth of 33.53 cm, followed by ‘Champion’ (29.08 cm), ‘Golden Delicious’ (28.00 cm), ‘Florina’ (27.80 cm), ‘Idared’ (26.60 cm) and ‘Reinette Simirenko’. These results indicate a higher resitance against drought of ‘Generos’ and ‘Champion’ cultivars which were able to reach the optimum shoot growth under water deficit conditions.

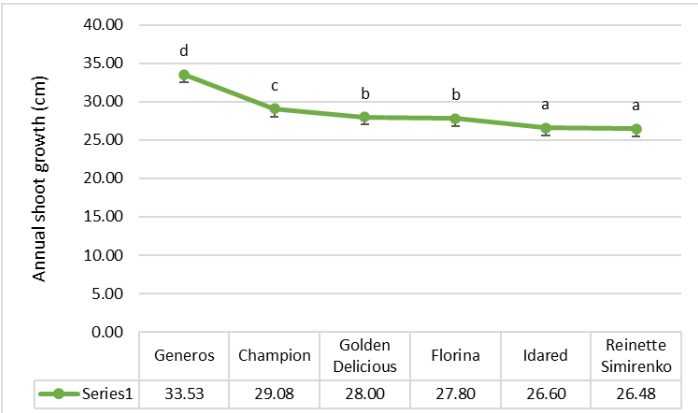

Fig. 3. Average annual shoot length of the apple cultivars under study. Different lowercase letters above the error bars indicate significant differences between the means at $p<0.05$

Canopy volume is another important factor responsible for a balanced growth, optimal fruit quality, and sustainable orchard practices. Canopy volume directly affects the amount of sunlight intercepted by the tree. Adequate light interception is essential for photosynthesis, which defines fruit development and quality (Robinson, 2004b). Excessive canopy volume can cause shading within the tree, reducing photosynthesis in the lower branches and leading to poor fruit color, size, and soluble solid content. Proper canopy management enhances air circulation, reducing humidity levels that encourage the occurance of fungal diseases like apple scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*). An appropriate canopy volume allows a more efficient application of pesticides and fungicides during pest and disease management practices (Jones and Aldwinckle et al., 2012). In high-density planting systems, smaller canopy volumes are preferred to prevent shading between neighboring trees, promoting higher yields per unit area (Lakso and Robinson, 1997). The results of canopy measurements indicate that canopy volumes were specific to high density orchards with a volume ranging between 0.18 and 0.32 m^3. The smallest volume was recorded in ‘Generos’ variety while the greatest in ‘Golden Delicious’. ‘Idared’, ‘Reinette Simirenko’ and ‘Florina’ shared the same canopy volume equals to 0.25 m^3 (Fig. 4).

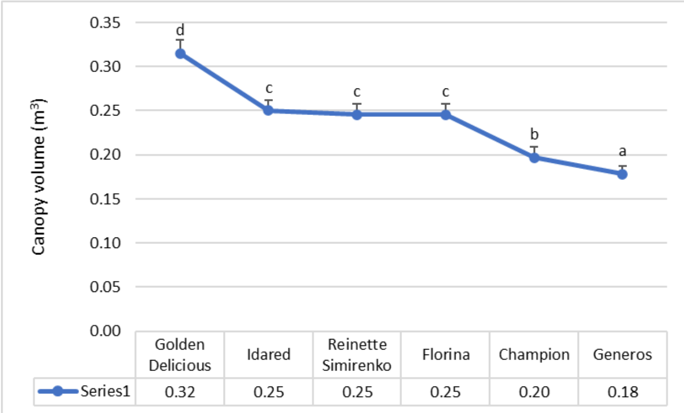

Fig 4. Canopy volume of the apple cultivars under study

In addition to other growth parameters, trunk cross-sectional area (TCSA) is another critical metric in high-density apple orchards, used to assess tree growth, vigor, and productivity. TCSA is directly correlated with a tree's overall size and vigor, providing a reliable measure of its growth. Typically, smaller TCSA values indicate trees that are less vigorous, which is desirable in high-density systems to prevent overcrowding and excessive competition (Robinson, 2004b). High-density orchards use dwarf or semi-dwarf rootstocks, which produce trees with smaller TCSAs. This facilitates better management and higher yields per unit area compared to traditional systems. TCSA values among the six apple varieties were ranging between 93.41 and 113.29 cm^2 (Fig.5).

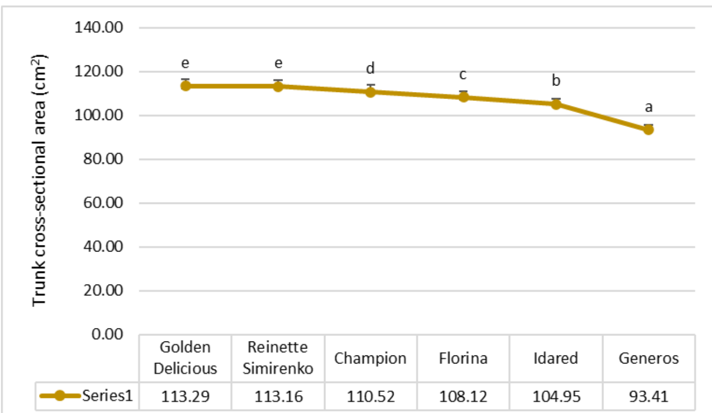

Fig. 5. Trunk cross-sectional area (TCSA) of the apple cultivars under study

These values are in accordance with other results reported by Westwood and Roberts (1970) who found similar values (between 100 and 110 for apple trees in the age of 15). Fruit yield TCSA indicates the extent to which potential bearing surface is actually being used to produce fruits.

Modern high-density orchard systems are designed to maximize yield per hectare by optimizing tree spacing, canopy management, and resource utilization. In this concern, yield per hectare becomes a critical factor in land-use efficiency. With limited agricultural land available, achieving high productivity has never been more important to sustain the growing global demand for apples (Lakso and Robinson, 1997). Higher yields per hectare contribute directly to increased income for growers. In commercial apple production, optimizing yield is essential for covering costs related to labor, inputs, and maintenance. Higher yields ensure a consistent supply of apples to meet consumers' demand, supporting market stability and export opportunities as well. The yield of apple cultivars under study varied between 25.38 and 40.48 t/ha. The most productive cultivars were 'Idared' with a yield equal to 40.48 t/ha followed by 'Champion' with 40,23 t/ha. Lower productivity was observed in 'Generos' (32.78 t/ha), Golden Delicious' (32.13 t/ha) and 'Reinette Simirenko' with a yield of 30.23 t/ha. The lowest productivity was exhibited by 'Florina' cultivar with a yield of 25.38 t/ha.

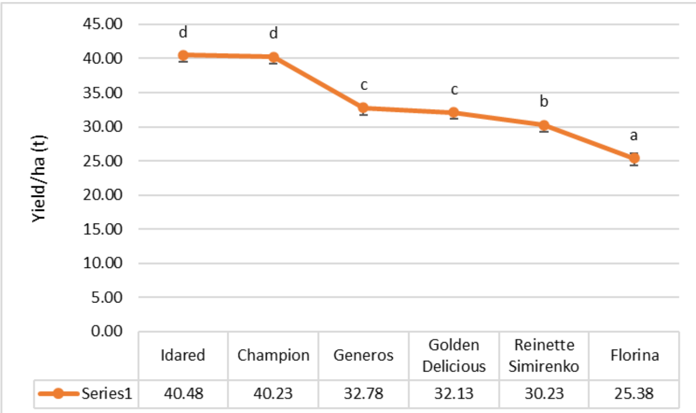

Fig. 6. Yield/ha of the apple cultivars under study

After yield, yield efficiency refers to the amount of fruit produced proportionally to the tree size,which is measured in terms of fruit yield per unit of trunk cross-sectional area (TCSA) or canopy volume. It is a critical parameter for assessing the productivity and sustainability of apple trees, especially in modern high-density planting systems. Furthermore, yield efficiency indicates how effectively a tree converts resources into fruit. High yield efficiency reflects optimized orchard practices, including nutrient management, pruning, and irrigation. There are several factors that influence yield efficiency inlcuding tree vigor, rootstocl selection etc. Dwarf rootstocks, such as M9 and M26, are commonly used in high-density orchards to control vigor and enhance yield efficiency (Anthony and Musacchi, 2021). High-efficiency rootstocks balance vegetative and reproductive growth, ensuring consistent yields. The yield efficiency obtained in the apple cultivars under study varied from 0,19 to 0,26, the heighest values being obtained for 'Idared' and 'Generos' cultivars, followed by 'Champion' (0.25 kg/cm^2) with no statistically significant differences between the means. The lowest yield efficiency was recorded in 'Florina' cultivar equal with 0.19 kg/cm^2. In dwarf rootstocks, yield efficiencies usually range from 0.5 to 1.5 kg/cm^2 TCSA in well-managed high-density orchards. Trees on these rootstocks are specifically bred for higher efficiency, making them the standard for intensive systems. In the case of semi-dwarf rootstocks, yield efficiencies are generally lower, between 0.2 to 0.7 kg/cm^2 TCSA, due to larger tree size and increased vegetative growth relative to fruit production (Robinson, 2004b). In high-density planting systems, where dwarfing rootstocks dominate, optimal yield efficiency values are closer to the higher end of the range (1.0–1.5 kg/cm² TCSA).

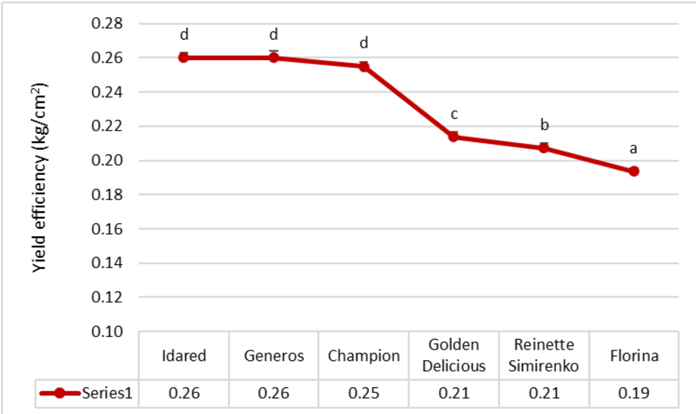

Fig. 7. Yield efficiency of the apple cultivars under study

CONCLUSIONS

From the outcome of this current investigation it is possible to conclude that tree growth parameters, yield, and yield efficiency are indispensable indicators of the productivity and sustainability of high-density orchards. Properly managed growth metrics such as trunk cross-sectional area (TCSA), tree height, canopy volume, and annual shoot length directly influence light interception, resource use efficiency, and overall tree vigor. These parameters play a pivotal role in optimizing fruit quality and quantity, which are essential for the economic viability of high-density systems.

The lower values of yield efficiency reported above which rather fit the yield efficiency of semi-dwarf rootstocks than dwarf rootstocks, might be explained by reduced rainfall and periods with water deficits which affected tree growth and development and entailed reduced productivity. However, it is important to mention that, even under drought conditions, 'Champion' and 'Idared' varieties were able to produce high yield as compared to the other cultivars.

REFERENCES

1. Anthony, B., & Musacchi, S. (2021). Dwarfing mechanisms and rootstock-scion relationships in apple. *Italus Hortus*, *28*(2), 22-36.
1. Atkinson, C. J., et al. (2012). Sustainable orchard management practices. *Journal of Horticultural Science and Biotechnology*.
1. Atkinson, C. J., et al. (2012a). Understanding the chilling requirement in apple and its implications for climate change. *Journal of Horticultural Science and Biotechnology*.
2. Barreiro-Hurle, J., et al. (2020). Polyphenol-rich apples and glucose metabolism. *Journal of Functional Foods*, 64, 103669.
3. Bondonno, N. P., et al. (2017). Flavonoid-rich apples and markers of cardiovascular health: A systematic review. *Food & Function*, 8(9), 3419-3427.
4. Boyer, J., & Liu, R. H. (2004). Apple phytochemicals and their health benefits. *Nutrition Journal*, 3(1), 5.

2. Chmielewski, F. M., et al. (2018). Climate change impacts on orchard water requirements. *Agricultural and Forest Meteorology*, 252, 44-52.
2. FAO (2020). The State of Food and Agriculture 2020. Food and Agriculture Organization.
5. Fereres, E., & Goldhamer, D. A. (2003). Suitability of water for agriculture: Guidelines for irrigation management. *Agricultural Water Management*, 56(3), 207-222.
6. Forshey, C. G., & Elfving, D. C. (1989). The relationship between vegetative growth and fruiting in apple trees. *Horticultural reviews*, *11*, 229-287.
3. Fujisawa, M., & Kobayashi, K. (2010). Apple quality and temperature changes: A comprehensive review. *Agricultural Meteorology*, 150, 107-115.
4. Gregory, P. J., et al. (2009). Climate change effects on pests and pathogens. *Global Change Biology*, 15(5), 1425-1438.
7. Hyson, D. (2011). "A comprehensive review of apples and apple components and their relationship to human health." *Advances in Nutrition*, 2(5), 408-420.
8. Jackson, J. E. (1980). Light interception and utilization by orchard systems. *Horticultural Reviews*, 2, 208-267.
9. Jones, A.L. and Aldwinckle, H. S. (2012). *Compendium of Apple and Pear Diseases.* APS Press.
10. Kumar, D., Srivastava, K. K., and Singh, S. R. (2019). Correlation of trunk cross sectional area with fruit yield, quality and leaf nutrient status in plum under North West Himalayan region of India. Journal of Horticultural Sciences, *14(1)*, 26-32.
11. Perez-Vizcaino, F., & Duarte, J. (2010). Flavonols and cardiovascular health: A review. *Current Medicinal Chemistry*, 17(36), 3634-3648.
12. Robinson, T. L. (2004a). Recent advances and future directions in orchard planting systems. In *VIII International Symposium on Canopy, Rootstocks and Environmental Physiology in Orchard Systems 732* (pp. 367-381).
13. Robinson, T. L. (2004b). Optimizing canopy management for high-density apple orchards. *Acta Horticulturae*, 636, 31-40.
14. Slavin, J. L. (2013). Fiber and prebiotics: Mechanisms and health benefits. *Nutrients*, 5(4), 1417-1435.
5. West, J. S., et al. (2015). Apple scab dynamics in the context of climate change. *Plant Pathology*, 64(6), 1091-1103.
15. Westwood, M. N., & Roberts, A. N. (1970). The Relationship Between Trunk Cross-sectional Area and Weight of Apple Trees1. *Journal of the American Society for Horticultural Science*, *95*(1), 28-30.
16. World Bank Climate Data. 2024. https://climateknowledgeportal.worldbank.org/country/moldova