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The effect of ageing on the tensile properties of greenhouses nets

Ines Tucman[1*], Ana Pilipović[1]

[1]University of Zagreb Faculty of Mechanical Engineering and Naval Architecture, Department of Technology, Chair for Polymer Processing, Ivana Lucica 5, 10000 Zagreb, Croatia

Abstract: Providing good protection for cultivated plants against weather conditions like hail, frost, and wind, as well as from animals like birds, insects, and wild boars, is important for enhancing plant growth and improving both production and quality. For this reason, plants are grown in covering systems (greenhouses) where covering materials play a major role. This paper analyses the effect of ageing on tensile properties of nets and the advantages of using nets as a covering part in greenhouses and explores their positive impact on plant protection and growth. The nets that were tested are made from different polymer materials, mostly polypropylene (PP) and high-density polyethylene (HDPE). The result shows that in the case of PP net (PA105N) and HDPE wind protection net (ZO95) the tensile strength decreases by 28% - 35% respectively after ageing. The elongation in most cases increases even up to 70% (net 70%). Additionally, there is a noticeable change in the shape of the nets after exposure to the atmospheric environment.

Keywords: ageing; nets; greenhouse; polymer materials; tensile properties.

1. Introduction

Greenhouses are fundamental to the advancement of facility agriculture and are crucial for achieving high-quality, efficient crop production. Accurate control of the greenhouse microclimate is a key technology for maximizing crop yield, quality, and efficiency. [1] There are different types of greenhouses with all-frame structures, including gable-shaped, tunnel-shaped/ quonset-shaped, and gothic arch-shaped. Greenhouses that are quadrant-shaped, hapel-shaped, semi-gable-shaped, and semi-tunnelshaped usually have transparent apricus roofs, opaque shady roofs, and solid walls. The latter four types are hybrid load-bearing structures that encompass both frames and walls. Of the various shapes, gable-shaped and tunnel-shaped greenhouses are the most commonly used for growing crops. [2] Currently, the greenhouses that once used glass covering are increasingly started using plastic materials. The world consumption of plastics in agriculture amounts yearly to 6.5 million tons. This shift is primarily due to the cost-effectiveness, lightweight nature, and ability to construct larger structures offered by plastics when compared to glass. The plastic material type (nets or films) to be used depends on several factors, mainly the local tradition. [3]

Plastic nets are used mainly in countries with tropical and Mediterranean climates. A major problem confronting Mediterranean greenhouse horticulture is the excess of heat during summer. One of the methods to alleviate the heat load is shading with nets. They play a crucial role in covering applications to improve micro-climatic conditions for crops and are protecting crops from weather conditions like hail, wind, snow, and heavy rainfall, primarily in fruit cultivation and ornamental plant cultivation. One of the key advantages of using nets as a covering material in greenhouses is their ability to improve air circulation and ventilation. Traditional covering materials like glass or plastic films can restrict the movement of air, leading to stagnant conditions and increased humidity. Nets, on the other hand, allow air to flow freely, creating a well-ventilated environment. This enhanced air circulation helps prevent the buildup of moisture, reduces the risk of fungal diseases, and promotes the exchange of gases necessary for photosynthesis. They are also perfect to be used to shade mushroom-beds and shelters for cattle breeding. [3,4,5,6]

*Corresponding author:
Email: inestucman1997@gmail.com

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Plastic net coverings offer many advantages and environmental benefits. In particular, net covering can enhance productivity, quality and homogeneity of plants and fruits throughout the year in hot and sunny regions. [7]

Furthermore, these nets find utility in safeguarding crops against virus-carrying insects and birds, as well as aiding in harvesting and post-harvesting procedures. The most used raw material extensively used for producing agricultural nets is high density polyethylene (HDPE). Additionally, polypropylene (PP) is also utilized for this purpose. [8]

Within the market, nets are defined as both woven and non-woven variations. To avoid misunderstanding, the following definition of plastic nets is proposed: a plastic net is a product made of plastic fibres connected with each other, in a woven or knitted way forming a regular porous geometric structure and allowing fluids (gases and liquids) to go through. [3,8]

Net types are characterised by different structural features like kind of threads, fabrics, shape and dimensions of fibres and meshing, by physical properties like weight, colours, shading factor, durability, porosity, air permeability and mechanical characteristics such as stress, strength at break and elongation. Normally the available dimensions of nets vary a lot for both the width and the length. The width usually varies from 1 m to 6 m or from 12 to 20 m (depending on the type of net) and the length from 25 m to 300 m. Wider nets are constructed by joining the required number of widths. A first classification of nets can be based on the material, the kind of fabric, the colour and additives used. [9,10]

This study investigates the impact of ageing on the tensile properties of greenhouse nets, focusing on how different materials are affected by ageing and whether they need to be changed more often or not. Six nets for a variety of applications, such as sun, wind, insect and hail protection made from various polymer materials, including HDPE and PP, were selected for testing. Parameters such as tensile force, strength, elongation, and changes in net shape after ageing were analyzed.

2. Materials and Methods

2.1. Materials

Different structural attributes such as material composition, thread type, thread dimensions, texture, mesh size, solidity, and weight distinguish various types of nets. Nets can also have different colour, transmissivity, reflectivity, and shading factor. In addition, different net types have different physical traits like air permeability and various mechanical properties including tensile stress, durability, strength, and elongation at break. In this work, classification of nets will be based on type of material. The most used material for agricultural nets is high density polyethylene (ρHDPE = 940-960 kg/m^3). It is a non-toxic material, which can be used in direct contact with plants; it is completely recyclable; easily convertible; resistant to water; durable, if stabilized to ultraviolet (UV) radiation agents are added in the correct quantity; and has good mechanical characteristics such as tensile strength in the range from 20 to 37 MPa, elongation in the range from 200 to 600%). Except for HDPE, polypropylene is also widely used. Polypropylene (ρPP = 900-910 kg/m^3) is used as raw material in the production of non-woven layers. This kind of membrane is in horticulture and in orchards applied as direct cover on plants to protect cultivations from rain, frost, or wind. Non-woven layers are characterized by a very low structural resistance and cannot be used as coverings of structural frames. PP is also used as fibers and filaments produced by extrusion and is used in agriculture for piping, sheeting, nets, and twines. [9, 10]

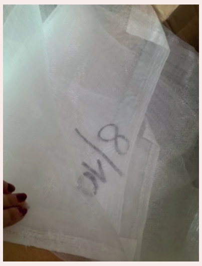
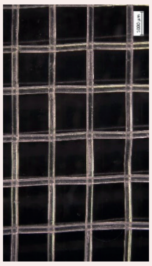
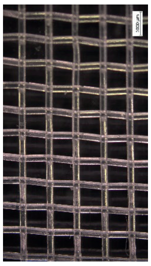
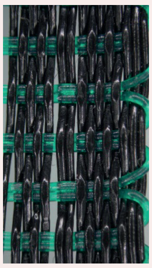
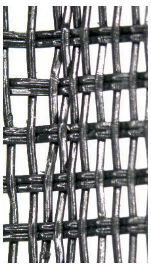
In this work, six types of commercially available nets were selected for various applications. Different nets (for different applications like sun, wind, insect and hail protection) made from the same type of material (HDPE) were selected, along with one net made from a different material (PP), to enable a more accurate comparison of properties and to determine whether the material affects these properties. Additionally, this approach aimed to assess whether such nets can withstand long continuous exposure to the sun's rays.. The **▶Table 1** shows images of the nets, also enlarged under a Digital microscope *Stemi 508*, from the manufacturer *Zeiss*. The scale bars in the magnified net images presented in **▶Table 1** are 1000 µm.

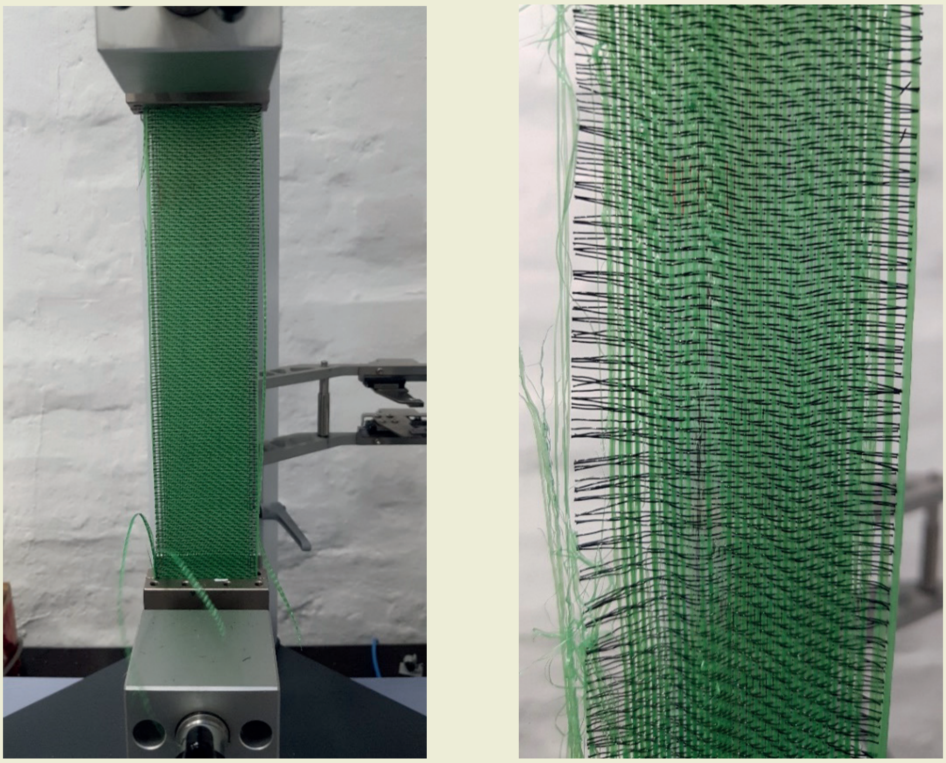
2.2. Methods

Six different types of nets were used in this research. From each net sample six specimens were cut off. Three of them were put in the ageing chamber. Dimensions of specimens, cut out of net samples, were 50 mm × 300 mm with gauge length 200 mm, in accordance with the ISO 13934-1:2013 (**▶Figure 1**). The nets test specimens were not folded over twice at the gripping areas, the grips of the tensile testing machine clamped the test specimens at the edges. During the test, none of the nets broke in the jaws. The thickness of nets is listed in **▶Table 1**.

Ageing was carried out in Solarbox xenon test chamber (**▶Figure 2**) that has xenon-arc light in the presence of moisture, so there is a possibility of regulating temperature, humidity and/or wetting. The radiant heat emitted by the Xenon Lamp in Solarbox xenon test chamber is continuously monitored and regulated using a Black Standard Thermometer (B.S.T.), which is positioned in the plane of the test panels near the

Table 1. Listed nets and their descriptions

Name of the net	Picture of the net	Net material	Description
8/10	  Thickness: 0.482 mm	-HDPE	- Anti-insect nets allow an effective protection against harmful insects in the context of biological and integrated pest management. White color ensures maximum brightness, and the different sizes of the hole allow the protection against various types of insects.
20/10	  Thickness: 0.54 mm	-HDPE	- Anti-insect nets allow an effective protection against harmful insects in the context of biological and integrated pest management. White color ensures maximum brightness, and the different sizes of the hole allow the protection against various types of insects.
PA105N	  Thickness: 0.272 mm	-PP	-Groundcover provides a clean surface to walk on while keeping the soil free from weeds. It is strong, durable, and permeable to water. It also reduces the water evaporation by keeping the soil moist. It drastically reduces herbicides and maintenance costs.
ZO95	  Thickness: 0.498 mm	-HDPE	- ZO[5 is HDPE UV stabilized net which is mostly used in protection against the wind from air currents and sun.
70%	  Thickness: 0.612 mm	-HDPE	- Shading nets create a better microclimate, reduce evaporati-on, avoid the sunburn, decrease the thermal shock, protect from hail and wind, create areas of privacy, with various effects depending on the density of meshes. The nets are supplied in standard rolls or in sewn cloths on demand.
APRO	  Thickness: 0.55 mm	- HDPE	-APRO is professional anti-hail net HDPE UV stabilized. Some properties of this net are: weft yarn: ø 0.32 mm, mesh size: 8.5x2.8 mm, black color shading: 16%, reinforcements: center and edges, widths: da 0,50 a 6 mt (from 0,50 to 6 mt), widths over 6 mt with sewing.



a) b)

Figure 1. Tensile test of nets: a) during the testing, b) after the testing

a) b)

Figure 2. Solarbox xenon test chamber: a) the whole chamber, b) nets in the chamber

samples. The B.S.T. allows for the control and display of the black standard temperature within a range of 35 °C to 100 °C. The significance of temperature in the weathering degradation process lies in the fact that the rate of chemical reactions tends to double with every 10 °C increase in temperature. As temperature plays a critical role in accelerating the ageing process, precise control of the B.S.T. during exposure to filtered Xenon radiation is crucial for ensuring accurate and reliable test results. Solarbox xenon test chamber has ultimate filtered Xenon light exposure and weathering instruments which simulate realistic natural outdoor weathering conditions. The ageing was done according to ISO-4892-2 at an irradiation of 550 W/m^2, a temperature of 65 °C and humidity 65% for 1000 h. Ageing in xenon test chamber in duration of 1000 h roughly corresponds to 3 years of actual ageing under atmospheric condition. After ageing, the specimens are marked with symbol K. Given that the goal of the work is to establish whether the tensile properties of the net have changed after ageing, the nets were tested before and after ageing. Tensile properties were tested on tensile machine Shimadzu AGS-X with max force 10 kN. All results are presented in ▶**Table 2**.

Figure 3. Curling of the nets after ageing

3. Results and Discussions

To understand the effects of ageing on the tensile properties of greenhouse nets, various observations were made before and after the ageing process. The analysis aimed to evaluate how prolonged exposure to environmental conditions impacts the physical characteristics of these nets. Initial findings indicate that the ageing process causes noticeable changes in the nets, such as curling, as depicted in ▶**Figure 3**. This section discusses these changes in detail, presenting the data on tensile force, strength, and elongation along with visual evidence of the physical alterations observed.

Results of tensile force and elongation is given in the ▶**Table 2** and ▶**Figure 4**. In the ▶**Table 2** is presented average values with standard deviation.

From the conducted tests, it can be concluded that the tensile force of all nets, although UV-stabilized, decreases during ageing, but their tensile elongation increases. For the PA105N net, the tensile force decreased by 27%, while for the ZO95 net, the tensile force decreased by 34%. The only net whose tensile force did not decrease is the 70% net; after ageing, its tensile force increased by 4%. The APRO and 8/10 nets experienced a slight decrease of around 3%, and the 20/10 net showed a tensile force decrease of 14%. All nets, except for the ZO95 net (whose elongation increased by 70%), did not show significant differences in elongation before and after ageing. For PA105N the tensile strenght decreases by 27%, for ZO95 decreased by 34%. The 70% net is only net that shows increase in tensile strenght. And other nets have slight decresed values which can be seen better in ▶**Figure 5**.

Comparing the results from the tables in many other research, it can be noticed that the results are very similar. In other studies, it is reported that anti-hail, anti-insect, and anti-wind nets made from HDPE have an elongation at break ranging from approximately 20% to 40%. In this research, the values similarly fall within

Table 2. Testing results

Name	Max. force, N	Break disp, mm	Break force, N	Max. break disp, mm	Max. Stress, N/mm^2
PA105N	775.816±61.9371	30.3970±3.42141	523.261±114.415	34.7582±0.44422	57.0453±4.55424
K-PA105N	567.382±19.2071	22.2418±2.53476	455.056±81.2193	24.9471±1.79342	41.7193±1.41226
ZO95	1445.15±107.791	41.8066±1.74068	1294.78±102.407	43.6695±0.67983	58.0379±4.32892
K-ZO95	958.072±324.002	62.6417±7.33512	871.508±350.793	74.1747±5.68667	38.4767±13.0120
70%	672.640±35.0809	41.6945±1.38087	216.116±30.6572	54.1693±2.78258	21.9817±1.14645
K-70%	699.033±49.0850	47.1527±4.07053	435.633±36.4331	60.6363±9.86550	22.8442±1.60410
APRO	268.194±25.4491	33.2070±4.17501	232.578±33.4858	35.8528±1.95411	9.75252±0.92542
K-APRO	260.450±10.0347	34.7823±1.39186	229.980±58.8926	38.1527±2.93355	9.47090±0.36489
20/10	557.525±35.8535	41.9526±3.13471	252.944±149.229	49.8252±1.76057	20.6490±1.32789
K-20/10	496.882±17.4388	42.1140±5.58894	363.989±62.0107	48.2915±7.00628	18.4030±0.64588
8/10	837.713±5.80287	38.2862±2.32484	661.409±168.481	40.8689±3.90539	34.7599±0.24080
K-8/10	823.190±47.4025	37.9974±1.70967	707.461±112.293	41.1302±1.55311	34.1573±1.96690

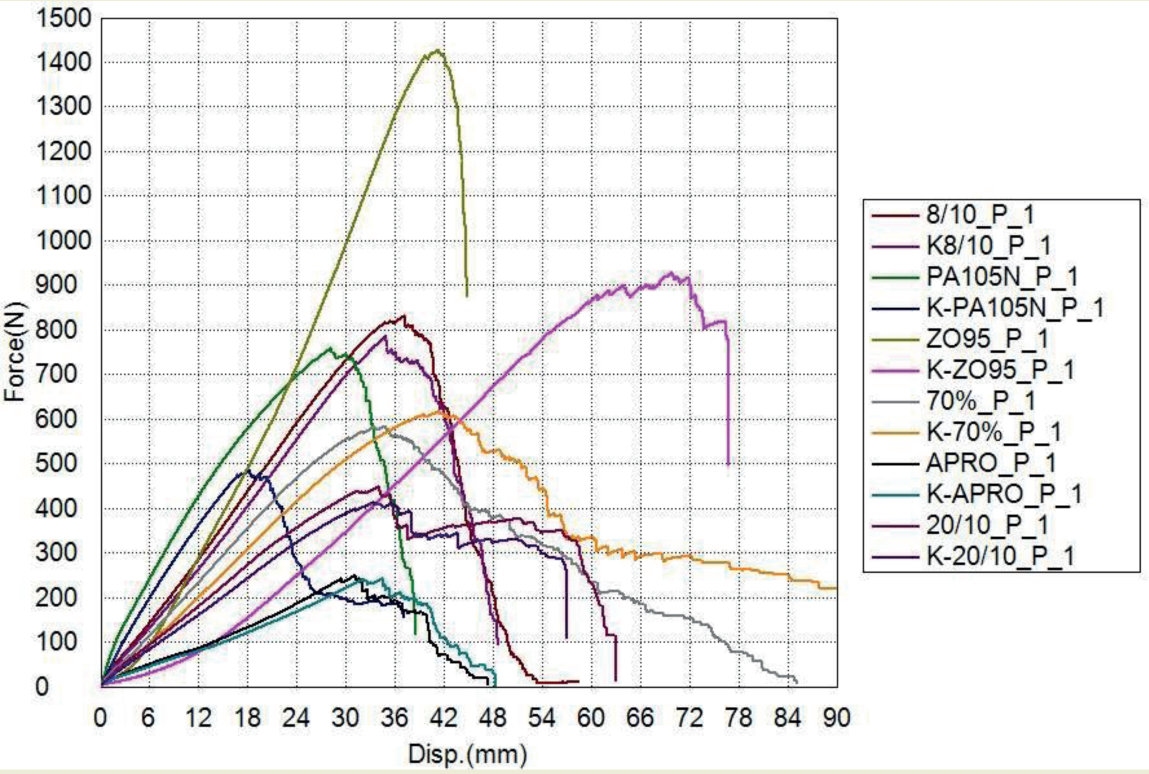


Figure 4. Tensile force – displacement curve (average curves for all nets)

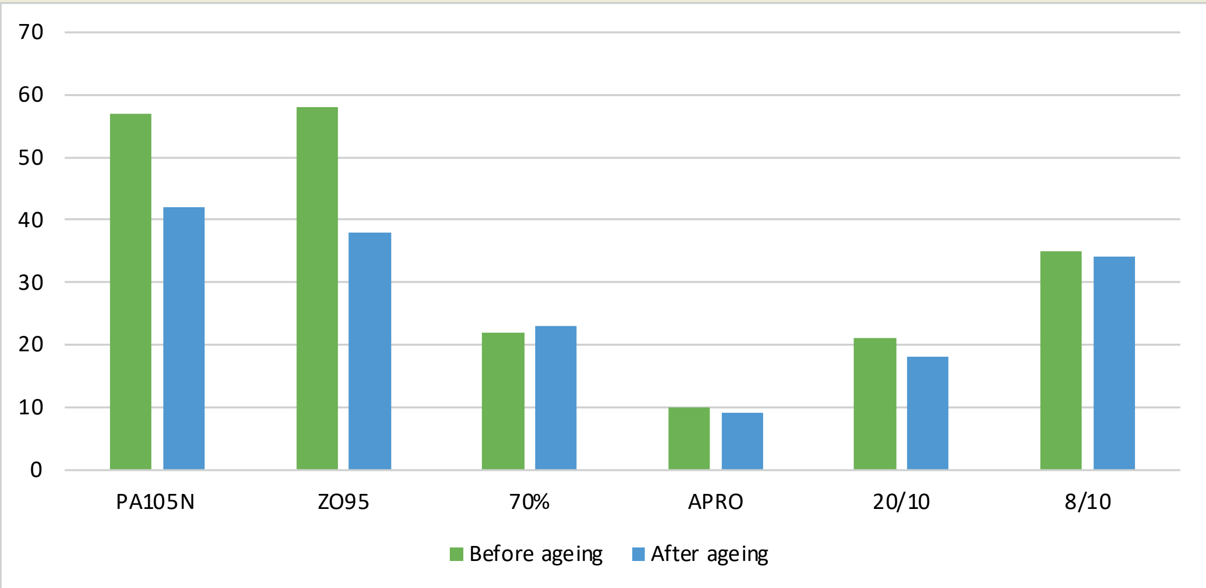


Figure 5. Comparison of tensile strength of the nets

this range. Tests have shown that the best properties are the nets that are mostly used in agriculture, HDPE nets. Compared to other studies, where the values for HDPE nets typically range around 25 N/mm^2 and some are around 7 N/mm^2. It really depends on type of the net. In one study, the max. break disp values are approximately 60 mm for windbreak nets used in agriculture align closely with our own testing results. Similarly, the tensile force values are also comparable as values are little bit higer. [11,12,13]

4. Conclusions

This paper examines the effect of ageing on various nets used as greenhouse covers for plants. The results indicate that the tensile force of the nets decreases with ageing, despite being UV-stabilized, but their elongation remains similar.

According to the standard in the Republic of Croatia, this chamber test simulates approximately 3 years of real-world conditions. It can be concluded that the nets maintain their properties and could continue to be used for an extended period without replacement. However, as ▶**Figure 3** illustrates, degradation is evident in the change of the net's shape; it no longer retains its original form and begins to curl. Interestingly, the net made from PP (while others are made from HDPE) exhibits similar properties, showing no significant difference between these two materials.

This test expedites the selection process of suitable materials for protecting greenhouse plantations (including plants, fruits, and vegetables). However, its efficacy heavily relies on seasonal variations and climate factors such as rainfall, hail size, sunlight intensity, and wind speed. It's crucial to note that in Croatia, the orientation of the greenhouse plays a pivotal role. In the continental region, it's advisable to use nets and films that allow higher light transmission, essential for early and late-season crop production. A north-south orientation is preferred with these materials. Conversely, in coastal areas, diffuse nets and films are more common. While they allow less sunlight penetration, they provide better thermal insulation in winter and effective shading in summer. The orientation of the greenhouse is less critical with these materials. Furthermore, the covering material must possess high transparency, transmitting at least 80% of the visible spectrum, up to 20% of the ultraviolet spectrum, and no more than 10% of the infrared spectrum.

After laboratory tests, which in this case correspond to 3 years of actual exposure to UV rays, the majority of tested nets showed that tensile forces and strength do not change over time. The PP mesh for covering the ground and the mesh against the wind showed slightly worse properties in terms of tensile strength. In further research, we will include the process of rain (i.e. immersion in water) and different percentages of moisture and see how this affects the properties of the nets. In addition to the nets, in future research it is also planned to examine the plastic films that are used to protect plants in greenhouses. Furthermore, in order to establish why such phenomena occur in future research, FTIR and TGA testing will be performed on all nets before and after ageing. Also a continuation of the study, there will be an analysis of the impact of ageing on meshes cut perpendicular to the manufacturing direction.

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Research ethics

Not applicable.

Author contributions

Conceptualization: Ines Tucman and Ana Pilipović, Methodology: Ines Tucman, Formal Analysis: Ines Tucman and Ana Pilipović, Investigation: Ines Tucman, Data Curation: Ana Pilipović, Writing - Original Draft Preparation: Ines Tucman, Writing - Review & Editing: Ana Pilipović, Visualization: Ana Pilipović, Supervision: Ana Pilipović, Project Administration: Ana Pilipović

Competing interests

The author(s) state(s) no conflict of interest.

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Data availability

The raw data can be obtained on request from the corresponding author.

Orcid

Ines Tucman https://orcid.org/0000-0003-4520-3584
Ana Pilipović https://orcid.org/0000-0003-1330-6458

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