EFFECT OF ARTIFICIAL WEATHERING ON PHYSICAL AND MECHANICAL PROPERTIES OF WOOD

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ABSTRACT – When wood is exposed outdoors, a combination of chemical and mechanical factors and solar radiation contribute to what is described as weathering, being the main degradation agent in this environment. This paper aims to investigate the effect of artificial weathering on mechanical and physical properties of *Eucalyptus* sp. and Cupiúba (*Goupia glabra*) woods simulating natural weathering effects. Samples were aged in UV radiation chamber with humidity and temperature control for 100, 200, 300 and 400 hours, considering aging cycles according to ASTM G154 (2006). Wood properties investigated were Conventional value of strength in static bending (f_M), Modulus of elasticity in static bending (E_M), strength in compression parallel to grain (f_{c0}) and Janka Hardness (f_H) according to ABNT NBT 7190 (1997). Effects of artificial weathering on wood properties were evaluated by statistical analysis at 5% significance level. Most of the wood properties investigated did not present significant changes with the aging performed, however, it was noted a decrease in the absolute values of the wood properties absolute values during the aging process. Only f_H of Cupiúba wood aged for 100 and 200 hours presented significative performance loss at the significance level considered, which can be related to changes on the wood surface due to weathering exposure.

Keywords: Artificial weathering, *Eucalyptus* sp, Goupia glabra.

EFEITO DO ENVELHECIMENTO ARTIFICIAL NAS PROPRIEDADES FÍSICAS E MECÂNICAS DA MADEIRA

RESUMO – Quando a madeira é exposta ao ar livre, uma combinação de fatores químicos e mecânicos e a radiação solar contribuem para o que se denomina intemperismo, sendo o principal agente de degradação nesse ambiente. Este trabalho tem como objetivo investigar o efeito do intemperismo artificial nas propriedades mecânicas e físicas de ***Eucalyptus*** *sp. e de Cupiúba (****Goupia glabra****) simulando efeitos naturais do intemperismo. As amostras foram envelhecidas em câmara de radiação UV com controle de umidade e temperatura por 100, 200, 300 e 400 horas, considerando os ciclos de envelhecimento de acordo com ASTM G154 (2006). As propriedades da madeira investigadas foram valor convencional de resistência à flexão estática (f_M), módulo de elasticidade à flexão estática (E_M), resistência à compressão paralela à fibra (f_{c0}) e dureza Janka (f_H) de acordo com a ABNT NBT 7190 (1997). Os efeitos do intemperismo artificial nas propriedades da madeira foram avaliados por análise estatística com nível de significância de 5%. A maioria das propriedades da madeira investigadas não apresentou alterações significativas com o envelhecimento realizado, porém, observou-se diminuição dos valores absolutos das propriedades da madeira durante o processo de envelhecimento. Apenas o f_H da madeira de Cupiúba envelhecida por 100 e 200 horas apresentou perda significativa de desempenho no*

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nível de significância considerado, o que pode estar relacionado a alterações na superfície da madeira devido à exposição ao intemperismo.

Palavras-Chave: Envelhecimento artificial, ***Eucalyptus*** *sp, Goupia glabra.*

1. INTRODUCTION

Among the materials used as raw material by the industry, wood is one of the most used since the beginning, for the manufacture of artifacts with little technology employed (Ahmed et al. 2017) to recent researches that aim at the improvement of its properties for more noble use (Peng et al. 2017; Song et al. 2018).

Trees that originate the wood come from two sources: native forests that present trees with distinct silvicultural properties and strong environmental appeal (Pasca et al. 2010; Vázquez-Cuecuecha et al. 2015; Almeida et al. 2017; Tuisima-Coral et al. 2017; Bäcklund et al. 2018) and planted forest with a focus on securing industry reserves (Piekarski et al. 2017; Ferro et al. 2018b, 2018a).

Brazil is prominent in the world in relation to its forest potential, since it presents in its territory, different biomes, among them the Amazon Forest (Steege et al. 2016; Cardoso et al. 2017; Pereira et al. 2017; Silva et al. 2018). There is an estimate that only the Amazon Forest region has 16 thousand species of trees, with the least part cataloged (Steege et al. 2016) and, in addition, an even smaller amount with its known properties (Cassiano et al. 2013; Christoforo et al. 2017).

Amazon Forest conservation is important for the environmental diversity maintenance of this important biome. The determination of the properties of these woods contribute to its rational use and sustainable management with minimum environmental impact (Almeida et al. 2013; Lahr et al. 2016; Ilha et al. 2018; Metcalfe et al. 2018).

As an alternative to the use of native wood from the Amazon Forest, in Brazil, wood from planted forests is also used, mainly those of the genus *Pinus* and *Eucalyptus*, used in pulp, paper and panels industries and to obtain massive structural pieces (Dougherty and Wright 2012; Almeida et al. 2016; Nogueira et al. 2018).

Among the ways of using wood already mentioned, its use in the building construction is one of the most important because it can be used as a structural member in houses and bridges, floors, among others (Araujo et al. 2016; Chen and Guo 2016, 2017; Dogu et al. 2017; Marsili et al. 2017; Ferro et al. 2018b). For this purpose, physical and mechanical properties of the wood are of interest for the structural design. The determination of these properties is performed according to standard codes (Icimoto et al. 2015; Kloiber et al. 2015; Missanjo and Matsumura 2016; Fank et al. 2017; Mahmud et al. 2017; Osuji and Nwankwo 2017; Nogueira et al. 2018; Rigg-Aguilar and Moya Roque 2018).

However, like other biological materials, wood is susceptible to environmental degradation. When exposed to ground air, a complex combination of chemical, mechanical and solar factors contribute to what is described as inclement weather, being the most important factor of degradation in this environment (Rivera-Nava et al. 2016; Clerc et al. 2017; Ayata et al. 2018; Callister Junior and Rethwisch 2018). The harmful effect of wood wear has been attributed to a complex set of reactions induced by several factors. The atmospheric factors responsible for the changes in this material are solar radiation (ultraviolet rays, visible light and solar irradiation), moisture content, temperature and oxygen (Ters et al. 2011; Oberhofnerová et al. 2016, 2017; Ouadou et al. 2017; Almeida et al. 2018).

Considering these factors, solar radiation is the most damaging component of the outdoor environment and initiates a wide variety of chemical modifications on the surface of the wood (Evans 2009; Froidevaux and Navi 2013; Kránitz et al. 2016; Žlahtič and Humar 2016; Pereira et al. 2017).

Wood exposed to the weather presents variations in the percentage and composition of its hemicelluloses, which can affect the degradation behavior. Regarding the causes and effects of photochemical degradation, the color change on the surface is usually characterized by the degradation of extractives and lignin (Yildiz et al. 2013; Garcia et al. 2014; Zborowska et al. 2015; Kerber et al. 2016; Liu et al. 2017; Guo et al. 2018; Reinprecht et al. 2018).

Accelerated artificial aging in ultraviolet radiation chambers technique has been frequently used in the study of material degradation, used mainly at the laboratory level. This procedure is widely used for polymeric materials. Problems of photodegradation have increased with use of polymers in exterior applications, causing physical and chemical changes that lead to discoloration, cracking, gloss loss and mechanical resistance decrease (Baysal 2012; Acevedo et al. 2013; Yildiz et al. 2013; Baysal et al. 2014; Jankowska and Kozakiewicz 2014, 2016; Mohammad-Fitri et al. 2017; Poletto 2017; Herrera et al. 2018).

Determination of possible losses in relation to the density and the mechanical properties, caused by the pathologies caused by the exposure through inclement weather, can predict structural damages. In this way, it is possible to analyze if the wood elements still remain consistent with the strength class specified in design, as determined by the NBR 7190 standard (ABNT 1997).

On the literature, there are a few studies considering the effect of artificial weathering on tropical hardwoods. Considering this, it is important to acknowledge how weathering affects tropical hardwood physical and mechanical properties of timber structural members under severe weathering conditions.

The aim of this work was to analyze the effect of accelerated artificial aging on the physical and mechanical properties of tropical hardwood Cupiúba (*Goupia glabra*) wood species, generally used in structures in civil construction, simulating the severe weathering conditions of the external environment, and compare the results of *Eucalyptus* spp. wood specie, a well-known wood specie used on civil and rural construction.

2. MATERIALS AND METHODS

For evaluating the weathering effects on physical and mechanical properties of wood, two wood species were chosen: *Eucalyptus* spp. and Cupiúba (*Goupia glabra*). Samples were taken from homogeneous wood batches with about 12% moisture content. For the static bending test, the length considered was 14×h, being h the height of the sample transversal section, and greater than the minimum limit of 1.8 cm established by the Brazilian code NBR 7190 (1997) “Timber structures design”.

Each wood species provided 48 samples with dimensions equal 2 cm × 2 cm × 64 cm. These samples provided two samples each one, with dimensions equal to 2 cm × 2 cm × 32 cm, being one for artificial weathering treatment and one control sample (Figure 1), totaling 96 samples for static bending tests. Samples for artificial weathering treatment were placed in the UV chamber to fill the entire compartment. Samples for the remaining tests were taken after the static bending test.

The EQUV-RC chamber of accelerated artificial weathering, made by EQUILAM, is used for aging conditions simulation in materials such as: plastics, paints, varnishes and coatings, woods, construction materials, cosmetic products, automotive lines

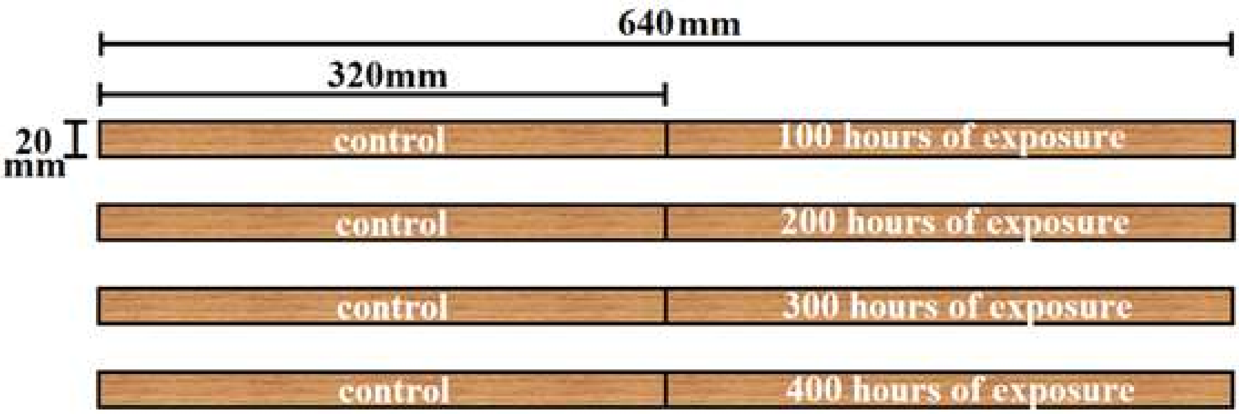

Figure 1 – Scheme of wood samples obtainment for artificial weathering treatment. (Dimensions in mm).
Figura 1 – *Esquema de obtenção de amostras de madeira para tratamento de intemperismo artificial. (Dimensões em mm).*

Table 1 – Density – Comparative between aged and control samples for each exposure period considered.
***Tabela 1** – Densidade - Comparativo entre amostras envelhecidas e controle para cada período de exposição considerado.*

Species	Density (g/cm³) Exposure period (hours)							
	100		200		300		400	
	Before	After	Before	After	Before	After	Before	After
Cupiúba	0.80 (3.55) A	0.77 (3.70) A	0.86 (7.96) A	0.82 (7.40) A	0.82 (7.51) A	0.79 (5.88) A	0.79 (5.23) A	0.75 (4.93) A
Eucalyptus	0.93 (7.03) A	0.94 (7.76) A	0.91 (7.40) A	0.91 (8.33) A	0.86 (9.77) A	0.84 (11.01) A	0.95 (6.67) A	0.95 (4.35) A

*Average values followed by coefficients of variation in parenthesis; ** Average values followed by the same letter presented statistical equivalence among themselves, at 5% significance level; *** Before = Control samples, After = Aged samples.
*Valores médios seguidos de coeficientes de variação entre parênteses; ** Os valores médios seguidos da mesma letra apresentaram equivalência estatística entre si, ao nível de signi fi cância de 5%; *** Antes = Amostras de controle, Depois = Amostras envelhecidas.*

products, adhesives, etc. Artificial weathering treatments were performed according to international code ASTM G154 (2006) "Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials". The equipment reproduces UVA/UVB radiation atmospheres (hot/humid), with condensation/thermal shock, simulating the effects of exposure to sunlight, rain and dew. Its radiation source is 8 fluorescent lamps (40 Watts each) with 340 nm wavelength (UVA) and irradiation power of 0.47 to 1.60 W/m²/nm. EQUV-RC chamber performs sample aging and degradation causing loss of brightness, change of color, turbidity, loss of strength, blisters, disintegration and oxidation.

Artificial weathering treatments were performed according to ASTM G154 (2006). This code prescribes exposure cycles according to the material being evaluated. In this paper Cycle 7 was considered, being the same used for test of wood coatings erosion. Cycle conditions are following: 8 hours of UV radiation at 60°C; 15 minutes of water spray; and 3 hours and 45 minutes of condensation at 50°C, totaling 12 hours/cycle. Average irradiation considered was 0.89 W/m^2/nm, using UVA lamps (340 nm wavelength).

Exposure periods considered were 100, 200, 300 and 400 hours, being about 8, 17, 25 and 33 cycles, based on Yildiz et al. (2013) studies. At the end of each exposure periods, 6 aged samples of each wood species were removed, and their physical and mechanical properties were determined, comparing these values to the respective control samples performance.

Characterization of wood was performed according to Brazilian code to investigate the effect of artificial weathering on wood properties. Density; Conventional value of strength in static bending (f_M), Modulus of elasticity in static bending (E_M), Strength in compression Parallel to grain (f_{c0}) and Janka Hardness (f_H) were determined. Considering that aging is more aggressive on the sample surface facing the chamber lamps, with direct exposure to radiation from lamps and water spray, the static bending tests were performed with de more aged surface in tension position. Mechanical tests were performed in a 25kgf capacity Universal Testing Machine (AMSLER).

Samples mass loss were evaluated though weighing wood samples before and after aging treatments. These values can be associated to changes in the chemical components of wood.

3. RESULTS

This section presents the results concerning physical and mechanical properties of Cupiúba and Eucalyptus wood, with and without artificial weathering treatment.

3.1 Physical properties

Tables 1 present results of Density and Mass loss for both wood species.

Table 2 – Mass loss for each exposure period considered.
***Tabela 2** – Perda de massa para cada período de exposição considerado.*

Exposure period (h)	Cupiúba			*Eucalyptus*		
	Mass (g)			Mass (g)		
	Before	After	**Mass Loss (%)**	Before	After	**Mass Loss (%)**
100	131.00	128.33	2.02	144.17	140.00	2.89
200	140.17	134.50	3.99	139.17	131.67	5.40
300	131.17	130.33	0.48	130.83	123.33	5.74
400	129.67	124.00	4.33	144.17	140.83	2.12

Table 3 – Cupiúba – Comparative between mechanical properties for each exposure period considered.
Tabela 3 *– Cupiúba - Comparativo entre as propriedades mecânicas para cada período de exposição considerado.*

Mechanical properties	Exposure period (hours)							
	100		200		300		400	
	Before	After	Before	After	Before	After	Before	After
f_M (MPa)	79.41 A (27.62)	69.4 A (41.32)	43.71 A (54.72)	40.54 A (37.50)	37.3 A (69.24)	41.1 A (59.99)	57.23 A (16.38)	40.43 A (42.69)
E_M (MPa)	18695 A (28.49)	17802 A (50.63)	12610 A (39.75)	9621 A (41.87)	12422 A (45.63)	9206 A (59.12)	16094 A (23.86)	11182 A (47.63)
f_{c0} (MPa)	50.45 A (8.35)	44.62 A (20)	44.62 A (9.32)	39.07 A (13.34)	46.8 A (12.50)	42.23 A (13.57)	46.93 A (5.92)	38.44 B (12.07)
f_h (kgf)	553.4 A (7.93)	508.49 B (4.39)	845.9 A (21.19)	638.6 B (19.77)	662.2 A (14.45)	552.6 A (20.88)	597.6 A (10.15)	526.6 A (13.58)

*Average values followed by coefficients of variation in parenthesis; ** Average values followed by the same letter present statistical equivalence among themselves, at 5% significance level; *** Before = Control samples, After = Aged samples.
Valores médios seguidos de coeficientes de variação entre parênteses; ** Os valores médios seguidos da mesma letra apresentaram equivalência estatística entre si, ao nível de signi fi cância de 5%; * Antes = Amostras de controle, Depois = Amostras envelhecidas.*

For Cupiúba wood, despite that average density among treatments presented statistical equivalence, there is a decrease tendency of values compared to the respective control samples with the exposure period increasing (Table 1). This tendency was not verified for Eucalyptus wood, with a decrease tendency until 300 hours and for 400-hour treatment there was no density decrease.

According to Table 2, higher values of Cupiúba wood mass loss were to 100-hour and 400-hour exposure period. For Eucalyptus wood mass loss, higher values were detected to 200 and 300 hours of exposure period. Such behavior may be explained by wood chemical depolymeralisation, degrading wood extractives the leaching of cell wall extractives and partial hydrolysis of the hemicellulose and cellulose on the sample surface, which consequently leads to the reduction of wood density (Jankowska and Kozakiewicz 2016).

3.2 Mechanical properties

Tables 3 and 4 present the results for mechanical properties for both wood species, being: Conventional value of strength in static bending (f_M), Modulus of elasticity in static bending (E_M), strength in compression parallel to grain (f_{c0}) and Janka Hardness (f_H).

4. DISCUSSION

According to Table 3 there is statistical equivalence among f_M, E_M and f_{c0} average values comparing performances of control and aged samples. Only f_H presented statistical difference for exposure

Table 4 – *Eucalyptus* – Comparative between mechanical properties for each exposure period considered
Tabela 4 *–* ***Eucalyptus*** *- Comparativo entre as propriedades mecânicas para cada período de exposição considerado.*

Mechanical properties	Exposure period (hours)							
	100		200		300		400	
	Before	After	Before	After	Before	After	Before	After
f_M (MPa)	102.87 A (15.42)	105.57 A (9.96)	110.89 A (4.27)	108.71 A (7.27)	106.38 A (4.26)	102.44 A (13.58)	100.95 A (15.91)	100.4 A (24.60)
E_M (MPa)	13163 A (12.37)	11842 A (7.54)	13370 A (9.15)	12734 A (4.47)	13607 A (11.80)	13010 A (10.08)	12387 A (22.48)	11928 A (21.64)
f_{c0} (MPa)	55.76 B (7.06)	61.02 A (6.90)	55.99 A (12.27)	62.18 A (9.31)	56.83 A (10.42)	59.34 A (12.12)	54.74 A (10.56)	63.65 A (13.78)
f_h (kgf)	632.2 A (16.20)	658.8 A (15.49)	715.1 A (9.34)	621.8 A (17.18)	625.8 A (24.82)	649.9 A (27.81)	682.1 A (25.58)	720.7 A (23.03)

*Average values followed by coefficients of variation in parenthesis; ** Average values followed by the same letter present statistical equivalence among themselves, at 5% significance level; *** Before = Control samples, After = Aged samples.
Valores médios seguidos de coeficientes de variação entre parênteses; ** Os valores médios seguidos da mesma letra apresentaram equivalência estatística entre si, ao nível de signi fi cância de 5%; * Antes = Amostras de controle, Depois = Amostras envelhecidas.*

periods equal to 100 and 200 hours comparing performances of control and aged samples.

Based on Table 3, it is important to point out that most of mechanical properties investigated presented decreasing tendency with the increasing of exposure period. Such behavior may be explained by the chemical change which wood underwent, changing cellulose particles and depolimerating wood hemicellulose, decreasing f_M and E_M properties (Kačíková et al. 2013).

Baysal (2012) verified hardness decreasing of 63% for Scots pine wood after artificial weathering treatment for 500 hours. This author compared this value with CCA (Chromated Copper Arsenate) treated Scots pine performance, observing that preservative treatment contributes to maintain hardness of wood under accelerated aging.

For *Eucalyptus* wood, mechanical properties investigated presented statistical equivalence between average values of control and aged samples for all exposure period considered. These average equivalences show that the exposure periods considered did not influence mechanical properties of this wood species. It is possible that greater values of exposure time (> 400 hours) may produce significative loss in mechanical properties considered.

Jankowska and Kozakiewicz (2016) analyzed 17 tropical wood species commercialized in Europe. These wood species have been aging treated by immersion in water, 70° C drying process and UV radiation exposure. This artificial weathering cycle was performed 140 times. Strength in compression parallel to grain was considered to investigate the loss of mechanical performance. Accelerated aging caused loss of strength in all wood species considered, and this effect was mainly affected by wood density and anatomy, besides, greater changes in the initial cycles of aging were observed. Massaranduba wood (*Manilkara bidentata* A. Chev.) presented 20% strength loss (92 MPa to74 MPa). Teca wood (*Tectona grandis* L.) presented 18% strength loss (58 MPa to 48 MPa) being the most resistant to accelerated aging.

According to Jankowska and Kozakiewicz (2014) and Jankowska and Kozakiewicz (2016) one of the main causes of loss of mechanical performance of wood under aging treatments can be related to the cyclic exposure conditions, which causes destruction of wood tissues and cracks. However, authors emphasize that there are many factors associated to loss of mechanical performance: microscopic factors (distribution of cellular elements of wood - parenchyma, fibers, vessels, etc.); macroscopic factors (juvenile wood and latewood incidences) or chemical composition of wood (extractives - resins, oils, tannins, etc.

As presented on Brazilian Standard ABNT NBR 7190 (ABNT 1997), the values for apparent density, compression strength parallel to the grain (f_{c0}) and modulus of elasticity (E_{c0}) for Cupiúba (*Goupia glabra*) are 838 kg/m³, 54.4 MPa and 13627 MPa, respectively. For *Eucalyptus punctuate*, the values are 948 kg/m³, 78.5 MPa and 19360 MPa, respectively. Observing the data presented above, the values of Density and Strength in compression parallel to grain presented by Tables 4 and 5 for both wood species are close to those established by the Brazilian code. Based on the equation $E_M = 0.90 \times E_{c0}$ for Dicotyledons wood from Brazilian code (ABNT 1997), being E_M the modulus of elasticity determined in static bending test and E_{c0} the modulus of elasticity determined in compression parallel to grain test, it is possible to compare normative prescribed values of E_M with the ones found in this study. Cupiúba 400 hours aged samples (Table 3) presented EM equal to 11182 MPa and according to the cited equation this value would be 12264 MPa (based on E_{c0} value).

Observing the study on the literature (Silva et al. 2018), the values of Cupiuba for apparent density ranged between 810 kg/m³ and 840 kg/m³, f_{c0} ranged between 47 MPa to 62 MPa and E_{c0} ranged between 12091 MPa to 15071 MPa. It can be verified that the aged sample presented close values of mechanical properties compared to the disposed on the literature. It may represent that weathering process is not significant to change mechanical properties. For a conclusive affirmation further researches are demanded, increasing the weathering time exposure and correlate natural and artificial weathering process.

5. CONCLUSIONS

Performing this investigation was possible to observe that there were not significant differences for most investigated properties after 100, 200, 300 and 400 hours of artificial weathering treatment. However, it is important to note that absolute values of all properties have decreased with the exposure period increasing.

There was significant difference between performances of control and aged samples only to Janka Hardness of Cupiúba wood treated for 100 and 200 hours of artificial weathering, which can be explained by changes on wood surfaces during aging process.

We believe that greater exposure periods may cause significant changes on properties of wood according to studies cited in the literature, as well as, considering more severe cycles of artificial weathering in future research, since wood is quite used in outdoor environments.

It can be emphasized the importance of this study since most of researches performed in accelerated aging of wood are focused on visual properties such as color changes and surface roughness. However, changes in chemical properties can produce loss of mechanical performances, affecting wood utilization as structural material in civil construction.

6. AUTHOR CONTRIBUTIONS

Marília Silva Bertolini, César Augusto Galvão de Morais, Tiago Hendrigo Almeida: Conceived and designed the analysis; collected and analysis the data.

Diego Henrique Almeida, Vinicius Borges de Moura Aquino, André Luis Christoforo, Francisco Antonio Rocco Lahr: Contributed data and analysis tools.

Vinicius Borges de Moura Aquino, Tiago Hendrigo Almeida, Marília Silva Bertolini, André Luis Christoforo: Conceived and designed the analysis; wrote the paper, research supervision and text review.

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