



Research Article

Mechanical, durability and solar reflectance properties of colored self-compacting concrete

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ABSTRACT

Urbanized areas are known to have significantly higher temperatures than rural areas. The Urban Heat Island (UHI) effect is caused by surfaces such as asphalt, buildings, and other heat-absorbing surfaces that store more heat than natural vegetation. Sunlight reflecting properties of building materials are improved with different applications. The present study investigates the mechanical, durability and solar reflectance properties of the colored self-compacting concrete. SCCs containing yellow, green, and black pigments were produced and evaluated. The fresh properties were determined with the slump, L-Box and V-funnel tests. Furthermore, compressive strength, solar reflectance and magnesium sulfate resistance tests were conducted. Yellow pigment added SCC showed a great potential (with the albedo of 0.42) in terms of solar reflectance and decreasing the contribution to the urban heat island effect.

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1. Introduction

Most people live in urbanized areas, which have a high density of buildings made of concrete or similar construction materials. Concretes produced with gray cement generally have a gray color and, depending on these properties, they absorb a high amount of solar energy and transmit it to the outside as heat (Sanjuán et al. 2022). The heat release mechanism, as is widely well known, has a growing impact on the urban heat island effect (Sen et al. 2022). The most effective way to reduce this effect is to increase the amount of sunlight that is reflected, or to increase the Albedo (Mlilwana and Kearsley 2022; Chen et al. 2019). The albedo of fresh concrete is varied between 0.35 and 0.40, and it decreases to 0.20 as it ages (Kaloush et al. 2008). Many factors, including the ingredients, influence the true albedo of concrete (Sweeney et al. 2011). A previous study conducted by Pomerantz et al. (2003) indicated that the albedo of concrete was generally proportional to the albedo of cement and the albedo of aggregates.

While the availability of local materials restricts the aggregates that can be utilized in concrete production,

the most effective way to make concrete more reflective is to replace cement with light-colored cement replacement materials or to use white cement together with color pigments. Boriboonsomsin and Reza studied the effects of the utilization of slag as a cement replacement material on the albedo and it was reported that the albedo of the hardened concrete can be increased by 71 % compared to the reference mixture (Boriboonsomsin and Reza 2007). In another research, Marceau and VanGeem (2008) found that a high albedo can be obtained by coating a concrete surface with photocatalytic agents (Krishnan et al. 2018).

Colored concrete was first used as an aesthetic element in architecture in the United States in the 1980s, when the color, produced by applying iron oxide pigments to the surface or incorporating them into the fresh concrete mixture (Falikman and Deniskin 2021). Colored concrete is now widely used in the production of prefabricated structural elements and non-structural artifacts such as façades and ceilings in all over the world (Hameed and Ali 2021; Junior et al. 2022; Miranda et al. 2019). Self-compacting concrete (SCC) is commonly used for casting these elements, and white cement and

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color pigments are combined in their manufacture. SCC, as a type of special concrete, can easily slide and flow inside different parts of the formwork due to its own weight, and it does not require vibration (Adhikary et al. 2022). This concrete must be highly flowable and cohesive in order to achieve full compaction (Wani and Ganesh 2022). The cohesiveness and segregation of SCC mixtures can be improved by incorporating viscosity-modifying admixtures (Hameed et al. 2022). Additionally, superplasticizer admixtures can improve the flowability of the mixture (Huang et al. 2018). Since its invention, colored SCC has a wide range of practical applications worldwide. Since the late 1990s, this type of iconic architectural concrete usage has increased dramatically. In addition, the market for colored concrete is anticipated to expand by 6% by 2025 (Jesus et al. 2023). However, the major issues with colored concrete are its high production and maintenance costs (López et al. 2016), and it needs optimizing in terms of costs.

This study discusses the advantages of colored SCC. Mechanical, durability and solar reflectance properties of the mixtures were also investigated since there are few studies on this subject in the literature, especially on the self-compacting concrete subject. In addition, in this

study, the role of colored concrete in reducing the heat island effect was investigated.

2. Materials and Method

Silica based aggregates were used as both fine and coarse aggregates. CEM II type (42.5R) white cement (WC) conforming to the EN 197(BS EN 197-1 2011) standard was also used. Maximum aggregate size of 20 millimeters was chosen to prevent segregation and its effects. All aggregates are colorless and suitable for painting processes. Density of the coarse and fine aggregates are 2.8 g/cm³ and 2.5 g/cm³, respectively. In addition water absorption amounts are 0.4 % and 0.2 % for coarse and fine silica aggregates. Gradation curves of the aggregates and chemical properties of the WC are presented in Fig. 1 and Table 1, respectively. A commercial polycarboxylate based superplasticizer was also utilized. Iron-oxide based three different pigments (green, yellow, black) were also used in the mixtures. The chemical compositions of the pigments are given in Table 2. The mix proportions of the concretes are presented in Table 3. The ingredients were mixed at the rate of 1.27 rad/s for 6 minutes.

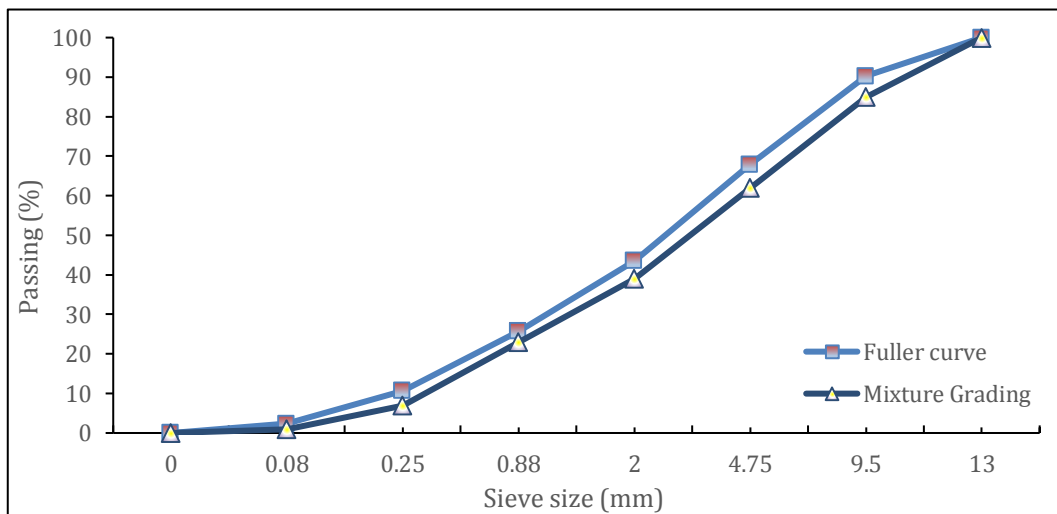


Fig. 1. Aggregate mixture gradation curves.

Table 1. Chemical properties of the white cement (provided by the supplier).

Component	%
Fe ₂ O ₃	3.5
CaO	60.48
Al ₂ O ₃	4.32
MgO	2.37
SiO ₂	-
Free CaO	1.69
SO ₃	2.61
Na ₂ O	-
K ₂ O	-
MnO	-
TiO ₂	-

Slump (EN 2009), L-box (CEN 2010) and V funnel (AFNOR 2010) tests were conducted to investigate workability properties of the fresh concrete. Compressive strength tests were performed on the cylindrical (150 x 300 mm) specimens at 3, 7, 28, 60, 90 and 180 days as per the requirements of TS EN 12390-3 (2003).

Table 2. Chemical properties of the pigments (provided by the supplier).

Pigment type	Green	Yellow	Black
SiO ₂ + Al ₂ O ₃	2.3	1.3	3.1
Fe ₂ O ₃	97	98.9	96.5
Density (g/cm ³)	0.7-0.8	0.4-0.65	0.7-1.1
pH	6-8	3.2-7.3	4-7

Table 3. The mixture proportions.

Sample	WC (kg/m ³)	Silica agg.-Coarse (kg/m ³)	Silica sand-Fine (kg/m ³)	Water/Binder	Pigment type	Pigment amount (by the w. of WC%)	Superpl. (by the w. of C%)
Ref.	400	850	750	0.43	-	-	1.5
SCC-G ₁	400	850	750	0.43	Green	2.5	1.5
SCC-G ₂	400	850	750	0.43	Green	5.0	1.5
SCC-G ₃	400	850	750	0.43	Green	7.5	1.5
SCC-Y ₁	400	850	750	0.43	Yellow	2.5	1.5
SCC-Y ₂	400	850	750	0.43	Yellow	5.0	1.5
SCC-Y ₃	400	850	750	0.43	Yellow	7.5	1.5
SCC-B ₁	400	850	750	0.43	Black	2.5	1.5
SCC-B ₂	400	850	750	0.43	Black	5.0	1.5
SCC-B ₃	400	850	750	0.43	Black	7.5	1.5

Sulfate attack on concrete specimens were also investigated in terms of compressive strength losses at 3, 7, 28, 60, 90 and 180 days. During the sulfate attack tests, two groups of samples were prepared. One group was kept in curing water, while the other was kept in a solution containing 10 percent magnesium sulfate. The concentration of magnesium sulfate was refreshed every 20 days until the end of the test period. Albedo values of the specimens were measured with an UV-VIS-NIR spectrophotometer (Fig. 2). In addition, rectangular specimens (24x24x5 mm) were prepared for the measurement (Fig. 3). Albedo properties were determined by examining wavelengths between 200 and 2500 nm. Mean percentages of reflections were measured, and albedo values for each sample were determined based on spectrophotometer readings.

In the first step of the experimental studies, the albedo value of the specimens was measured after 28 days of curing. The average of three measurements of the spectral reflectance of each specimen was recorded.

**Fig. 2.** UV-VIS-NIR spectrophotometer.**Fig. 3.** Albedo test samples.

3. Results and Discussion

The albedo values of the samples are given in Fig. 4. The test results range from 0.29 to 0.42. SCC-Y3 had the highest albedo, but SCC-test B3's result was the lowest, as expected (Kaloush et al. 2008). Albedos decreased as black pigment content increased.

Slump, L-box and V-funnel test results are shown in Figs. 5-7 respectively. Workability of the samples decreased on the inclusion of pigments. The value of slump flow varied between 712 and 725 mm for all mixtures conforming to the limits of EFNARC ((category of SF2) EFNARC 2002). The filling ability of the pigment added mixtures decreased due to the high-water absorption characteristics of pigments. In accordance with the present results, previous studies have demonstrated that pigment inclusion increases water demand of the concrete mixtures (Jesus et al. 2023; Hunek and Szafraniec 2021; Ghadban and Abdulrehman 2022).

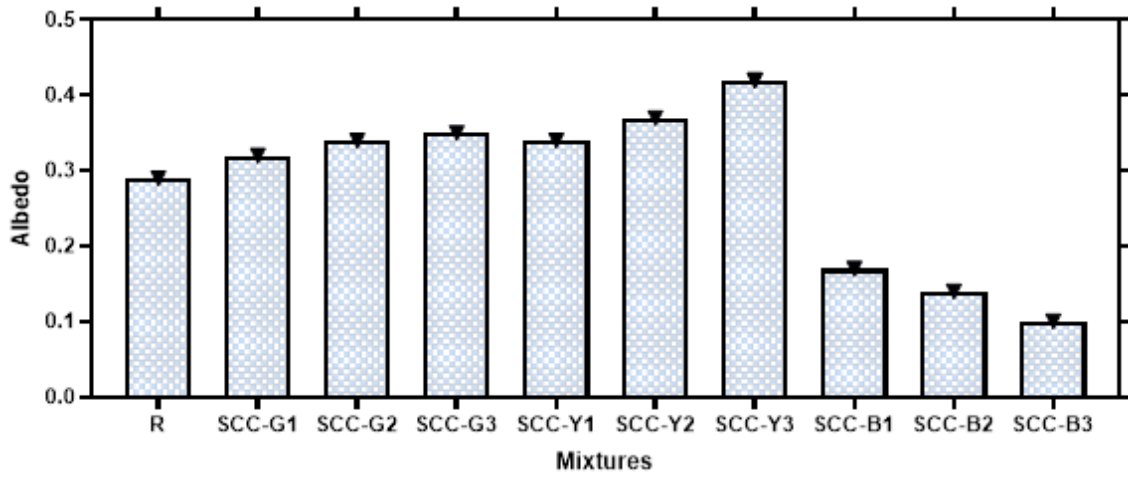


Fig. 4. Albedo of test samples.

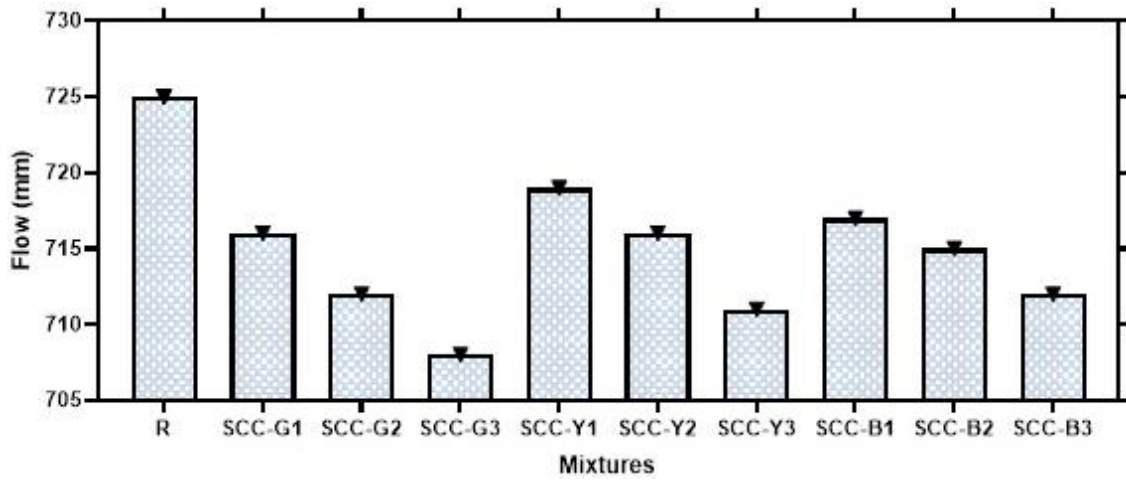


Fig. 5. Slump test results.

It was obtained that V-funnel times varied between 14 and 25 sec. (Fig. 7) and all samples were in the class of VS2 according to the ENFARC on the basis of viscosity (EFNARC 2002). In Fig. 6, there is a clear trend of increasing blocking ratios varied from 0.81 to 0.91 for all

mixtures. The blocking ratios of the mixtures were classified as PA2. The blocking ratios of the mixtures were classified as PA2. These results are in parallel with similar studies (Hunek and Szafraniec 2021; Ghadban and Abdulrehman 2022).

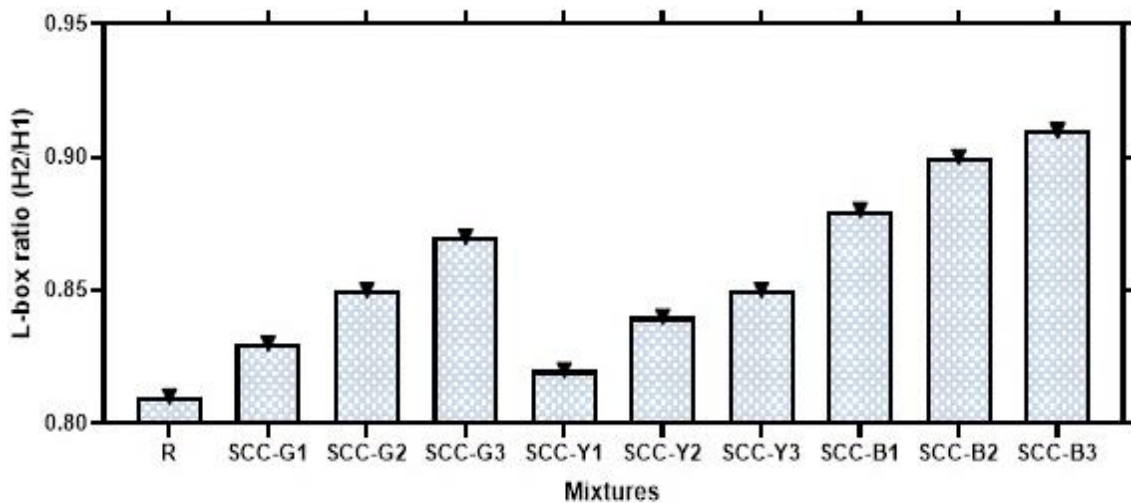


Fig. 6. L-box test results.

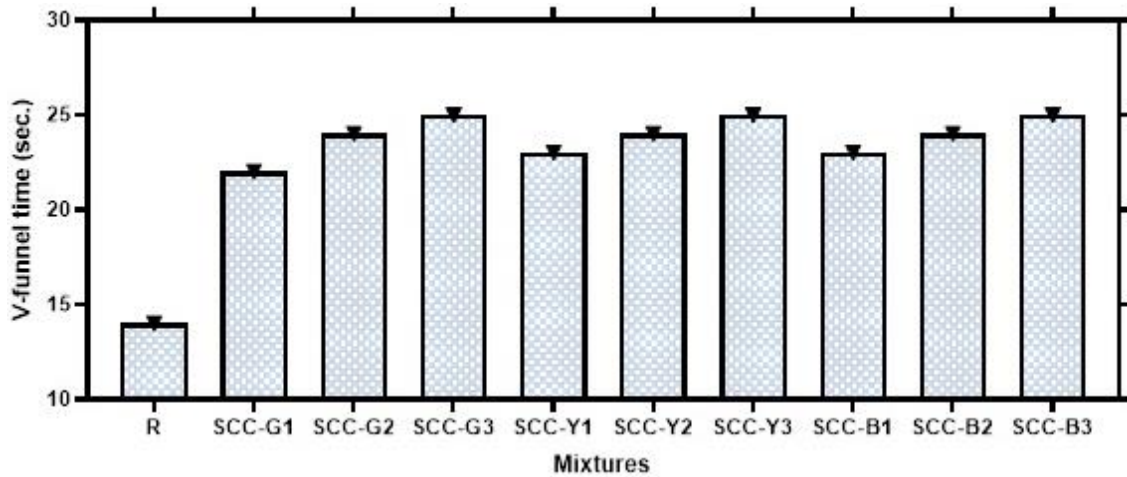


Fig. 7. V-funnel time.

Compressive strength test results at 7, 28, 60, 90 and 180 days are presented in Fig. 8. Compressive strengths increased for all samples with the increasing curing time (Kovačević et al. 2021; Akinpelu et al. 2019). Moreover, the pigment inclusion had very limited effect on the compressive strengths since all mixture had the cement and water to binder contents (Hoang et al. 2022; Djamila and Mohamed 2018).

The resistance of specimens to magnesium sulfate decreased with exposure time, as shown in Fig. 9. The most deleterious effect was obtained for the SCC-B3 mixture at 180 days and, compressive strength losses increased for all samples depending on the exposure time. These results are also compatible with the literature results (Zhao et al. 2019; Yang et al. 2023; Mostofinejad et al. 2020).

4. Conclusions

In this study, some mechanical, durability and solar reflectance properties of colored self-compacting concrete were investigated. Based on the experimental test results, following results can be drawn:

- SCC-Y3 sample showed the highest albedo, and black pigment added samples reflected the lowest albedo results as expected.
- Due to the high-water absorption characteristics of pigments, the filling ability of the pigment-added mixtures decreased. Moreover, the addition of pigment increased the water demand of concrete mixtures.
- The pigment inclusion had a negligible effect on the compressive strengths, as all mixtures contained the same proportions of cement and water to binder.
- The magnesium sulfate resistance of all samples decreased with the increasing time.

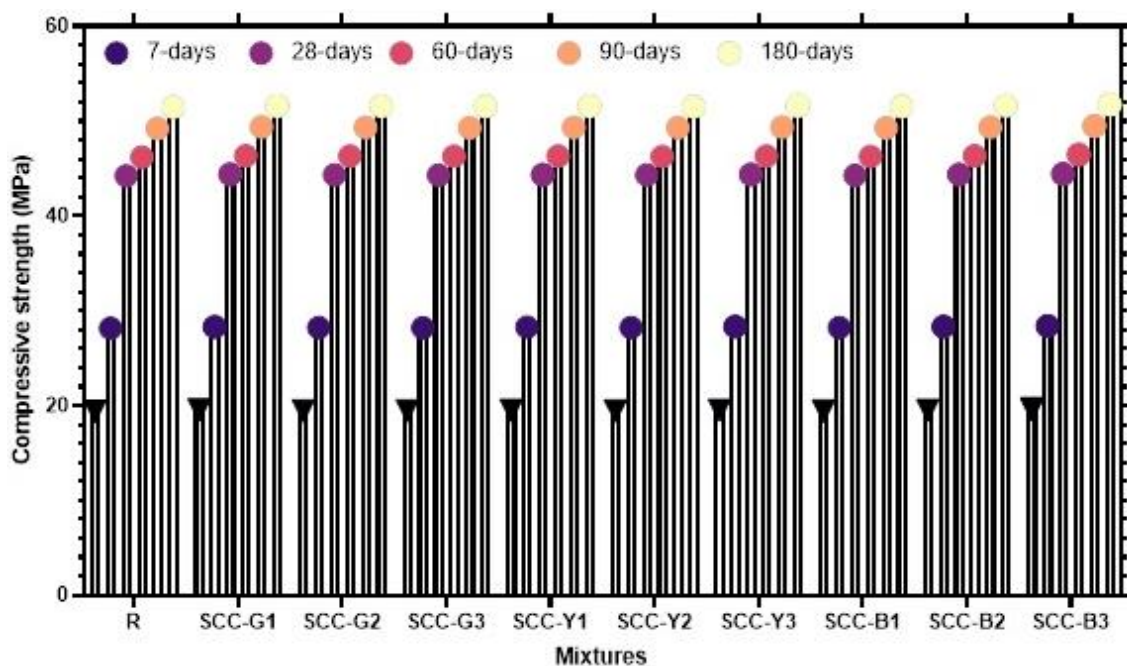


Fig. 8. Compressive strength test results.

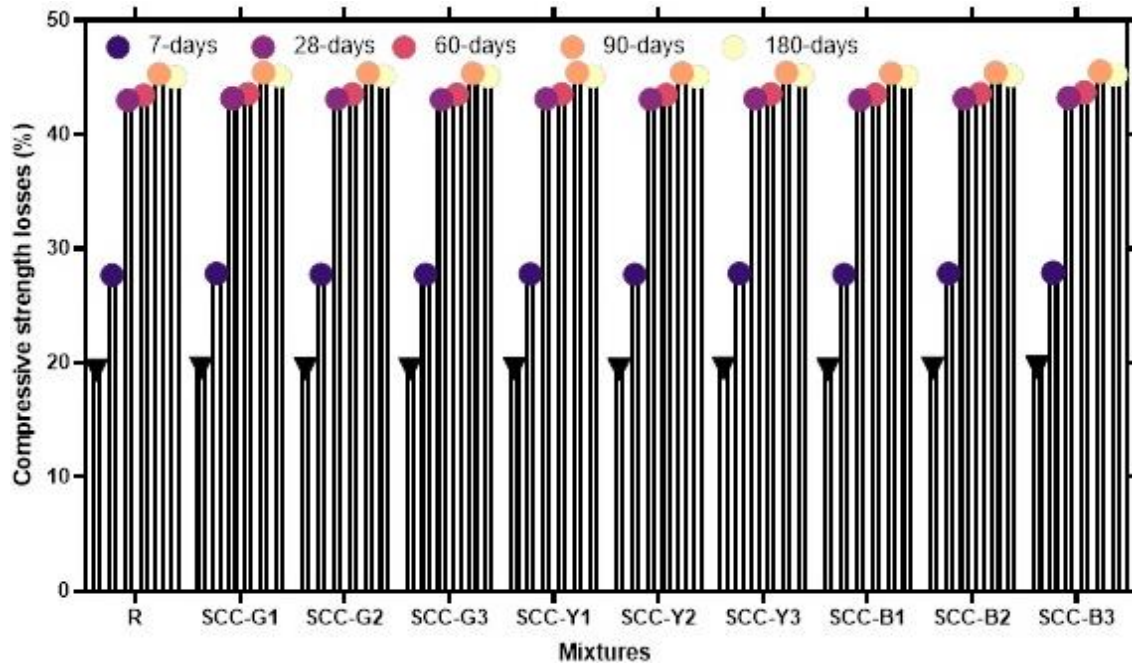


Fig. 9. Compressive strength losses (%).

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Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

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