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Research Article

Using Waste Foundry Sand As Sustainable Construction Material

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ABSTRACT

India's rapid industrialization and urbanization have led to substantial waste generation, posing significant environmental challenges. Among these wastes, the byproducts of metal industries, such as waste foundry sand (WFS), offer potential solutions for sustainable construction. This study investigates the feasibility of using WFS as a partial replacement for fine aggregate in M20 grade concrete. The experimental program involved incorporating WFS at varying percentages (0%, 10%, 20%, 30%, 40%, and 50% by weight) and assessing the impact on the compressive strength of concrete, complemented by the addition of a plasticizer (1% by weight of cement). The results demonstrated that up to 20% replacement of fine aggregate with WFS significantly enhances the compressive strength of concrete, achieving increases of 40.4% and 56.5% for 7 and 28 days of curing, respectively. Beyond 20% replacement, the compressive strength declined. This research highlights the potential for utilizing industrial waste in concrete production, promoting sustainable construction practices by reducing the reliance on natural resources and addressing waste management challenges.

Keywords: *waste foundry sand, plasticizer, compressive strength, durability, sustainable construction.*

INTRODUCTION

India's industrialization and urbanization have generated substantial waste, including gases, liquids, and solids. This has led to the daily production of significant amounts of waste, posing a major environmental concern. Concrete, a crucial material in high demand globally, particularly in the construction industry, contributes to this issue. Continuous development activities have led to environmental degradation due to the increased demand for aggregates and the inadequate supply of resources to meet this rising demand in both quantity and quality. The building industry is pivotal to infrastructure development in the twenty-first century, and the high cost of concrete can be mitigated by utilizing waste materials, such as metal industries' byproducts like waste foundry sand.

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Utilizing these waste products as building materials can help address some of the environmental impacts. Sand used in metal casting industries often has a finer grain size than common natural sand. After the metal casting methods are completed, the burned sand is discarded as a waste product known as "waste foundry sand." Using spent foundry sand as a partial or complete replacement for fine aggregate in concrete produces cost-effective, high-strength concrete. Concrete is a composite material made up of coarse aggregate, fine aggregate, cement, admixtures, and water, each of which contributes to the total strength. Partial or complete material replacement affects various properties of concrete.

This study aims to investigate the feasibility of using leftover foundry sand as a partial replacement for fine aggregate in concrete. The experiment involves mixing leftover foundry sand into M20 grade concrete at various percentages (0%, 10%, 20%, 30%, 40%, and 50% by weight). Metal foundries employ a large amount of metal in the casting process, and foundry sand is a high-grade silica sand produced as a byproduct during the production of both ferrous and nonferrous metal castings. Annually, the output of foundry sand ranges from 6 to 10 million tonnes. Foundries obtain high-grade, size-specific silica sands for use in their molding and casting processes. Unprocessed sand is often of higher quality than conventional bank-run or natural sands, which are commonly used for filling in construction projects. Sand casting remains the most commonly used procedure for mold casting.

The building industry and concrete makers are increasingly turning to existing materials instead of seeking appropriate aggregates for concrete. As steel production expands, industrial waste, such as spent foundry sand, is generated and can be utilized to make concrete. Foundry sand aggregate is commonly regarded as a structural component in civil engineering. An extensive analysis was conducted to analyze the compressive strength characteristics of concrete made from waste foundry sand and plasticizer. This study focuses on the importance of employing spent foundry sand, reviews previous research in this field, and addresses the materials used in concrete sample preparation, mix design approach, ingredient quality, and experimental methodologies for the mechanical and durability aspects of concrete. The experimental results are then described and analyzed. The study seeks to assess the durability and physical properties of concrete made from residual foundry sand and plasticizer.

Previous studies have highlighted the potential benefits of using waste foundry sand in concrete. Manoharan et al. (2018) investigated the effects of foundry sand as a fine aggregate replacement on the compressive strength, porosity, sulphate attack, and XRD characteristics of cement mortar. They found that metal foundries manufacture foundry sand, which can be used in concrete to increase its strength and longevity. Sastri et al. 2018 studied the correlation between workability, compressive strength, split tensile strength, and flexural strength in M20 and M30 grade concrete. Siddique and Mehta (2020) found that replacing sand with WFS increased 28-day compressive strength by 8.3-17%, splitting tensile strength by 3.6-10.4%, and modulus of elasticity by 1.7-6.4%, depending on the WFS concentration. Their study indicated continuous improvement in mechanical properties over a 365-day period. Nwofor and Ukpaka (2016) evaluated the proportion of foundry waste suitable for partially replacing fine sand aggregate. Their experiments revealed that 15% foundry sand is suitable for grade 20 concrete preparation. They used the least squares approach to predict compressive strength in WFS concrete design. Sandanayake et al. (2020) examined the use of spent foundry sand in cementitious concrete, concluding that reusing foundry sand holds great potential for developing environmentally friendly and sustainable concretes. Vilayatkar et al. (2021) focused on the proportion of foundry sand that may be used as a cementitious material, noting exceptional compressive and flexural strength results.

This study aims to acquire strength and durability data on concrete incorporating used foundry sands and fly ash. The findings of this study will be used to develop material standards for concrete containing recycled foundry sand for architectural precast concrete panels and other similar applications. This should result in increased usage of spent foundry sand in the production of concrete for various applications, contributing to sustainable construction practices.

MATERIALS AND METHODS

Materials

The goal of evaluating different material qualities is to ensure compliance with codal standards in order to develop a concrete mix with a certain strength. The following items were utilised in this investigation.

Waste Foundry Sand

Foundry sand is a high-quality silica sand produced as a byproduct of the ferrous and nonferrous metal casting industries. It has been used for millennia as a moulding casting material because to its strong heat conductivity. Raw sand is utilised in various foundry procedures, and it is enhanced by adding binders and additives (Table 1). Based on the binder technique utilised, foundry sand is divided into two types: clay-bonded (green) sand and chemically bonded sand. Clay-bonded or green sand, as the name implies, uses clay as a binder, while chemically bound sand uses chemicals as binders. Green foundry sand typically comprises 85-95% silica sand, 4-10% bentonite clay as a binder, and 2-10% carbonaceous additive to enhance casting surface polish. It also has residues of oxides including MgO, K2O, and TiO2. Chemically bonded sand, also known as chemical foundry sand, is made up of 93-99% silica sand plus around 1-3% chemical binder. The silica sand and chemicals are fully combined, and a catalyst starts the process that cures and hardens the mould mass. Epoxy resins, sodium silicates, furyl alcohol, and phenolic urethanes are among the most regularly used chemical binders. Carbonaceous additions give green foundry sand a black appearance, while chemical foundry sand is pale in colour. Green foundry sand is chosen for moulding operations, while chemical foundry sand is utilised for both mould and core forming activities, which need more strength to survive the heat of molten metal.

Table 1 Sieve analysis of waste foundry sand

Total weight of sample = 500 gm

Sr. No.	Sieve size	Wt. retained	Cumulative wt.	Percentage retaining	Percentage passing
1.	4.5mm	15	15	1.5	98.5
2.	2.36mm	28	43	4.3	95.7
3.	1.18mm	22	65	6.5	93.5
4.	600micron	382	447	44.8	55.2
5.	150micron	498	945	94.8	5.2
6.	75micron	33	978	98.1	1.9

Plasticizer

There are several chemical admixtures on the market that increase the workability qualities of concrete. These are added to concrete to minimise the amount of water in the mixture while simultaneously improving its workability and strength. Depending on the qualities of the materials, we may use some excess water in concrete; nevertheless, this tends to reduce the durability and strength of the concrete. The usage of plasticizer is a possible solution to this issue. Plasticizers, also known as high-range water reducers, are chemical admixtures used in concrete. Plasticizers are thought to be a very effective element in concrete. These include sulphonated melamine formaldehyde condensates (SMF), sulphonated naphthalene formaldehyde condensates (SNF), polycarboxylate ether superplasticizers (PCE), modified sulphonates, and others. Plasticizers are available in a variety of brands, each with a unique dose and composition. This research employed Conplast SP 430 G8, a sulphonated naphthalene polymer made by Fosroc Company. It takes the shape of a dark liquid that disperses rapidly in water. It decreases water content by up to 25%, resulting in high-quality concrete that retains its workability.

Ordinary Portland Cement (OPC)

The investigation utilised a single quantity of Grade 43 Ordinary Portland Cement (OPC). It was fresh and devoid of lumps. Cement was properly kept to avoid loss of its characteristics due to moisture exposure. Table 2 lists the cement's physical qualities as determined by several tests, as well as the matching BIS: 8112-2013 standard for that parameter.

Table 2: Properties of OPC 43 Grade Cement

Sr. No.	Characteristics	Value Obtained experimentally	Value specified by BIS: 8112-2013
1.	Specific Gravity	3.13	-
2.	Standard Consistency	30.5%	-
3.	Initial Setting Time	125 minutes	30 minutes (minimum)
4.	Final Setting Time	250 minutes	600 minutes (maximum)
5.	Compressive Strength 7 days 28 days	 34.85 N/mm^2 47.34 N/mm^2	 33 N/mm^2 43 N/mm^2

Properties of coarse aggregates

The coarse aggregates used were a mixture of two locally available crushed stones of 10 mm and 20 mm size in 50:50 proportions. The aggregates were washed to remove dirt and dust and then dried to surface dry condition. The specific gravity and other properties of the coarse aggregates are given in Table 3. The sieve analysis of the coarse aggregates was done, and the results of the sieve analysis are shown in Tables 4 and 5. After proportioning of coarse aggregates, fineness modulus was obtained as given in Table 4.5 respectively.

Table 3: Properties of coarse aggregates

Colour	Grey
Shape	Angular
Maximum Size	20 mm
Specific Gravity	2.65
Water Absorption	1.0%

Table 4: Sieve analysis for coarse aggregates (10 mm size)

Total weight of sample = 2000 gm

BIS- Sieve Designation	Weight Retained on sieve (gm)	Cumulative weight retained (gm)	Cumulative %age weight retained	%age passing
80 mm	Nil	Nil	Nil	100
40 mm	Nil	Nil	Nil	100
20 mm	Nil	Nil	Nil	100
12.5 mm	9	9	0.45	99.55
10 mm	588	597	30	70
4.75 mm	1269	1866	93.76	6.24
2.36 mm	125	1991	99.55	0.45

Properties of fine aggregates

The fine aggregates used are natural river sand and it was obtained from locally available building material store. The preliminary tests for the physical properties were conducted on fine aggregates and the results are shown in Table 6.

Table 5: Physical properties of fine aggregates

Sr. No.	Characteristics	Value obtained experimentally
1.	Fineness modulus	2.74
2.	Specific gravity	2.70
3.	Silt content	4.18%
4.	Water absorption	1.09%
5.	Grading zone	II

Sieve analysis of fine aggregates

In the presented research, WFS has been used as a partial replacement for fine aggregate. So, the sieve analysis was carried out to determine the fineness modulus and to draw the grading curve of fine aggregates and WFS.

Table 6: Sieve analysis of fine aggregates

Total weight of sample = 2000 gm

Sr. No.	Sieve size	Wt. retained	Cumulative wt.	%age retaining	%age passing
1.	4.5mm	Nil	Nil	0	100
2.	2.36mm	2	2	0.1	99.9
3.	1.18mm	3	5	0.25	99.75
4.	600micron	802	807	40.35	59.65
5.	150micron	1024	1831	91.55	8.45
6.	75micron	151	1981	99.05	0.95

Table 7: Sieve analysis of waste foundry sand

Total weight of sample = 500 gm

Sr. No.	Sieve size	Wt. retained	Cumulative wt.	%age retaining	%age passing
1.	4.5mm	15	15	1.5	98.5
2.	2.36mm	28	43	4.3	95.7
3.	1.18mm	22	65	6.5	93.5
4.	600micron	382	447	44.8	55.2
5.	150micron	498	945	94.8	5.2
6.	75micron	33	978	98.1	1.9

A comparative graph of the gradation of natural sand and WFS is shown in Figure 1. The waste foundry sand gradation is mostly close to the limits for fine aggregates used in concrete. It is worthwhile to note that the grading of used foundry sand is too fine to satisfy the specifications of fine aggregate. Hence, the waste foundry sand can replace the fine aggregates in cement concrete to some extent only.

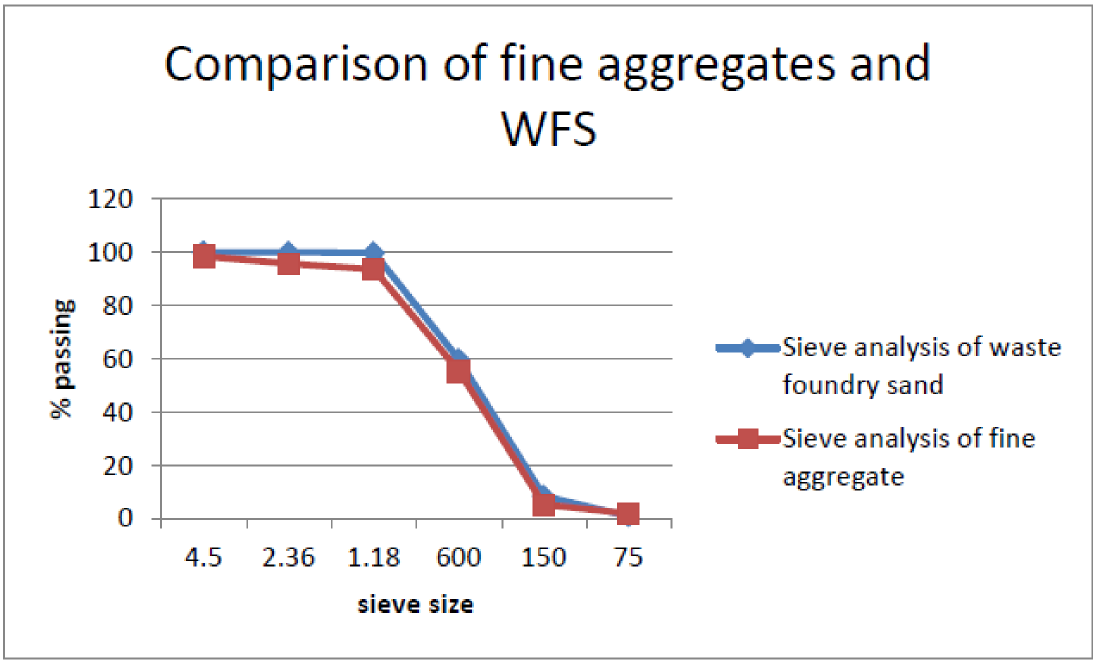

Figure 1: Comparison of sieve analysis of fine aggregates and WFS

RESULTS AND DISCUSSION

Mix design by Indian standard recommendations

Concrete mix design is the process of determining quantities of materials in the form of ratios of three key ingredients: cement, sand, and coarse aggregates. Concrete may be proportioned by mass or volume, however the water cement ratio is often represented by mass. The properties of concrete in both fresh and hardened stages are predetermined. The primary goal of concrete mix design is to determine the appropriate proportions of materials to provide the desired workability, strength, and durability. The current inquiry comprises the formulation of a concrete mix for M20 grade concrete. The guidelines provided in codes BIS: 10262-2009 and BIS: 456-2000 have been used to develop concrete mixes.

Table 8: Stipulation for proportioning

Grade designation	M-20
Type of cement	OPC 43 grade conforming to BIS: 8112
Maximum nominal size of aggregate	20 mm
Minimum cement content	320 kg/mm^2
Maximum water-cement ratio	0.42
Workability	50 mm (slump)
Degree of supervision	Good
Type of aggregate	Crushed angular aggregate
Maximum cement content	450 kg/m3

Calculation of cement content

Cement content = 157.6/0.40 = 394 kg/m3

Volume of coarse aggregates = 0.60

Volume of fine aggregates = 0.40

Table 9: Proportion of different materials

Water	Cement	Fine aggregates	Coarse aggregates
157.6 liters	394 kg	786.27 kg	1179.40 kg
0.42	1	1.99	2.99

Compressive strength tests of concrete

The cement, coarse aggregates (10 and 20 mm), fine aggregates, and waste foundry sand were all weighed individually. First, the cement and leftover foundry sand were combined dry and evenly. Fine aggregates were added to the mixture in dry form. The coarse aggregates were blended to provide a homogeneous distribution throughout the batch. Plasticizer was introduced first, followed by water. The ingredients were then hand blended for 3 to 4 minutes until completely combined. Concrete's compressive strength was tested using cubes of 150 mm x 150 mm x 150 mm. The cube molds were cleaned and oil applied. Then the concrete was poured into the cube molds. To guarantee optimum compaction, concrete molds were vibrated. The surface of the concrete was completed level with the top of the mould using a trowel. The completed specimens were allowed to solidify in air for 24 hours. After 24 hours of casting, the specimens were taken from the moulds and put in the laboratory's water tank, which was filled with drinkable water (Figure 2). Specimens were removed from the curing tank at ages 7 and 28 days. Surface water was wiped away, and specimens were analyzed immediately after being removed from the curing tank. Figure 3 depicts the compressive strength of concrete cubes as evaluated using a Universal Testing Machine (UTM). The force was steadily applied without shock until the specimen failed; therefore the compressive strength of concrete cubes was determined.

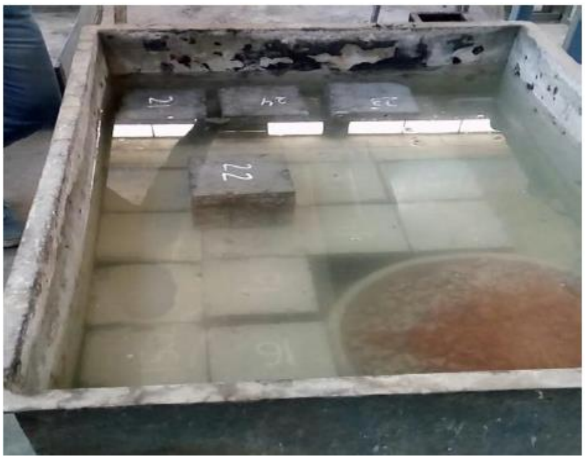

Figure 2: Curing of the casted cube specimens

Figure 3: Compressive strength testing using UTM

The compressive strength of all the mixes was measured at 7 and 28 days of age for varying amounts of waste foundry sand substitution with fine aggregates and plasticizer. Table 10 shows the average compressive strength for various replacement levels of waste foundry sand (0%, 10%, 20%, 30%, 40%, 50%) and the addition of plasticizer (1% by weight of cement) at the conclusion of different curing periods (7 days and 28 days). Figures 4 and 5 illustrate the relative compressive strength of several concrete mixtures after 7 and 28 days of curing.

Table 10: Test results for compressive strength of concrete

Mix	WFS(%)	Plasticizer(%)	Compressive Strength (N/mm^2)	
			7 Days	28 Days
F0P0	0	0	22.35	36.85
F1P1	10	1	26.21	43.32
F2P1	20	1	31.38	57.68
F3P1	30	1	19.30	47.39
F4P1	40	1	14.125	43.87
F5P1	50	1	13.67	34.37

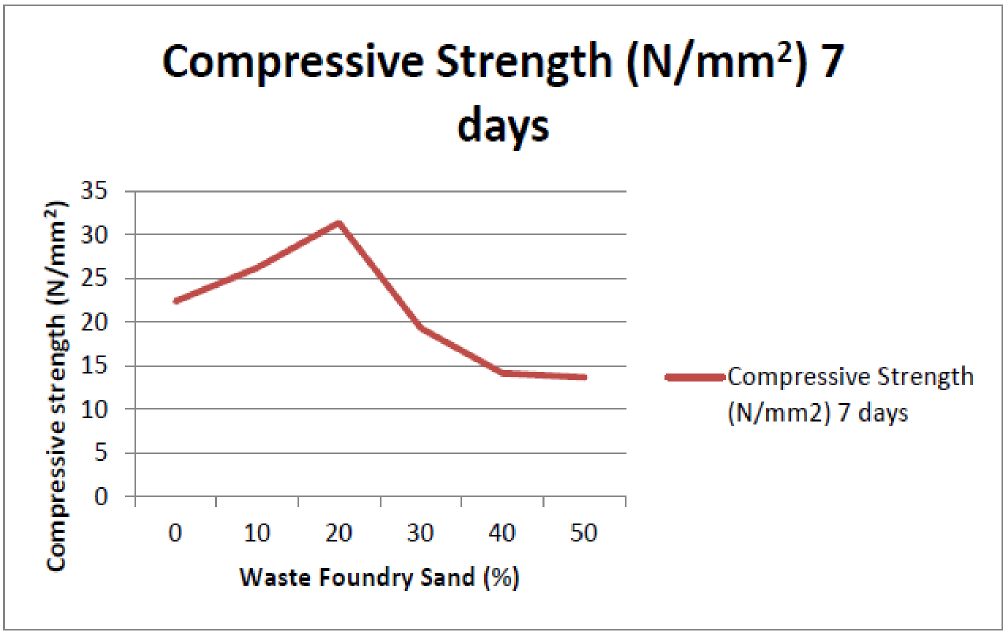

Figure 4 Compressive strength with different replacement levels of WFS (7 days)

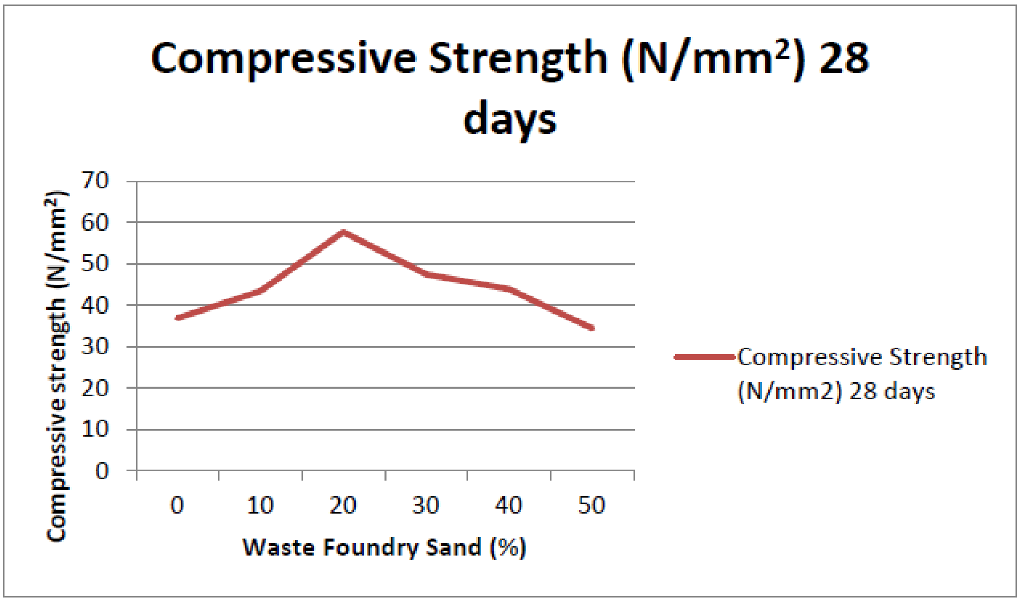

Figure 5 Compressive strength with different replacement levels of WFS (28 days)

Figures 3 and 4 show that adding more foundry sand, up to 20% replacement in concrete, enhanced compressive strength relative to the control mix. However, when the quantity of foundry sand surpassed the amount of fine aggregate in the concrete, the compressive strength steadily fell.

CONCLUSIONS

The use of recycled materials such as waste foundry sand in the construction industry addresses both waste management challenges and environmental impacts while significantly promoting sustainable development by reducing the consumption of natural resources. This investigation aimed to study concrete's durability and mechanical properties using waste foundry sand and plasticizer. A total of 24 concrete specimens were prepared by partially replacing fine aggregates with waste foundry sand (0% to 50%) and adding plasticizer (1% by weight of cement). Based on trial results, a 0.40 water-cement ratio was selected for all mixes. Tests for workability were performed on freshly prepared concrete, and compressive strength was tested after 7 and 28 days of curing. Statistical analysis was conducted on the compressive strength results. It was observed that there is an increase in the compressive strength of concrete up to 20% of waste foundry sand.

- With 10% of waste foundry sand and 1% of plasticizer added the increase in compressive strength is 17.27% for 7 days and is 17.55% for 28 days.
- With 20% of waste foundry sand and 1% of plasticizer added, the increase in compressive strength is 40.4% for 7 days and 56.5% for 28 days.
- Thereafter, this compressive strength starts decreasing from 30% to 50% of waste foundry sand.

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Conflict of Interest
The authors declare that they have no known competing financial interests or personal relationships that could appear to influence the work reported in this paper.

Author's contribution
Satinder Kaur Khattra: Writing the original draft, methodology, investigation, data curation, and conceptualization. **Sarvesh Kumar:** Methodology, Formal analysis, Investigation, Writing-original draft, communication, Review and editing.

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