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Development and Sensory Evaluation of Antioxidant and Protein-Enriched Energy Bars using Amla Pulp, Pumpkin Peel Powder and Pumpkin Seed Powder

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Abstract: ***The increasing demand for healthy, convenient, and functional snack foods has encouraged the development of value-added products enriched with natural bioactive ingredients. The present study aimed to develop antioxidant and protein-enriched energy bars using amla pulp (Phyllanthus emblica), pumpkin peel powder, and pumpkin seed powder, while promoting the utilization of fruit and vegetable processing by-products. Three formulations were prepared, namely T_0 (control), T_1 (15% amla pulp, 10% pumpkin peel powder, and 10% pumpkin seed powder), and T_2 (20% amla pulp, 15% pumpkin peel powder, and 15% pumpkin seed powder). The energy bars were prepared using oats flour and dates paste as base ingredients and evaluated for sensory attributes including colour, flavour/taste, texture, and overall acceptability using a 9-point hedonic scale. The results revealed that the moderately enriched formulation (T_1) achieved the highest scores for colour (8.80 ± 0.10), flavour/taste (8.40 ± 0.12), texture (8.50 ± 0.14), and overall acceptability (8.60 ± 0.09), indicating superior consumer preference. The highly enriched formulation (T_2) exhibited comparatively lower sensory scores due to increased acidity and fibre content. Cost analysis demonstrated a gradual reduction in production cost with increasing incorporation of fruit and vegetable by-products, with T_2 showing the lowest cost of production (Rs. 172.00/kg). The findings indicate that moderate incorporation of amla pulp, pumpkin peel powder, and pumpkin seed powder can successfully enhance the nutritional quality, antioxidant potential, and protein content of energy bars without compromising sensory acceptability. The study highlights the potential of utilizing underexploited food processing by-products for the development of sustainable, cost-effective, and health-promoting functional snack products.***

Keywords: Energy bars, Amla pulp, Pumpkin peel powder, Pumpkin seed powder, Antioxidants, Functional foods, Sensory evaluation, Sustainable food processing.

I. INTRODUCTION

Modern consumers increasingly seek foods that provide not only nourishment but also health-promoting benefits (Mena et al., 2024). Functional foods have emerged as an important category of products capable of delivering physiological benefits beyond basic nutrition (Singh et al., 2026). Among these products, energy bars have gained popularity because of their convenience, portability, extended shelf life, and nutrient density (Jain et al., 2026). Traditionally, energy bars are formulated using cereals, nuts, sweeteners, and fats. However, recent developments in food science have focused on enhancing their nutritional profile through incorporation of bioactive-rich fruits, vegetables, and food processing by-products (Saravanan et al., 2026).

Food processing industries generate substantial quantities of waste materials including fruit peels, pomace, seeds, and vegetable residues (Fernandes et al., 2026). These by-products often contain valuable nutrients and bioactive compounds that can be effectively utilized in food formulations. Their incorporation into value-added products contributes not only to improved nutritional quality but also to sustainable waste management practices (Boudalia et al., 2026).

Amla (*Phyllanthus emblica* L.) is recognized as one of the richest natural sources of vitamin C and contains abundant polyphenols, tannins, flavonoids, and antioxidants (Ghorpade and Somwanshi, 2026). Pumpkin peel is a rich source of dietary fibre, carotenoids, minerals, and phenolic compounds, while pumpkin seeds provide high-quality plant protein, healthy fats, and essential minerals (Kassa and Teferi, 2026). The combination of these ingredients offers excellent potential for developing nutrient-dense functional foods with enhanced antioxidant and protein content.

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Although several studies have investigated the use of cereals, fruits, nuts, and seeds in energy bars, limited information is available regarding the combined utilization of amla pulp, pumpkin peel powder, and pumpkin seed powder (Sharma et al., 2026). Therefore, the present study aimed to develop antioxidant and protein-enriched energy bars using these ingredients and evaluate their sensory acceptability and economic feasibility.

II. MATERIALS AND METHODS

A. *Procurement of Raw Materials*

Amla fruits, pumpkin peel powder, pumpkin seed powder, oats flour, dates paste, honey, peanuts, vegetable oil, and flavouring agents were procured from local markets. All ingredients were cleaned, sorted, and stored under hygienic conditions prior to use.

B. *Formulation of Energy Bars*

Three formulations were developed:

T_0 (Control): Conventional energy bar without enrichment.

T_1 (Moderate Enrichment): Incorporation of 15% amla pulp, 10% pumpkin peel powder, and 10% pumpkin seed powder.

T_2 (High Enrichment): Incorporation of 20% amla pulp, 15% pumpkin peel powder, and 15% pumpkin seed powder.

C. *Preparation of Energy Bars*

The dry ingredients were accurately weighed according to formulation requirements. Dates paste and honey were mixed thoroughly to prepare a binding matrix. Oats flour, pumpkin peel powder, pumpkin seed powder, and peanuts were blended uniformly before incorporation into the binder. The mixture was pressed into trays, allowed to set, and cut into uniform rectangular bars. The prepared bars were packaged and stored for sensory evaluation.

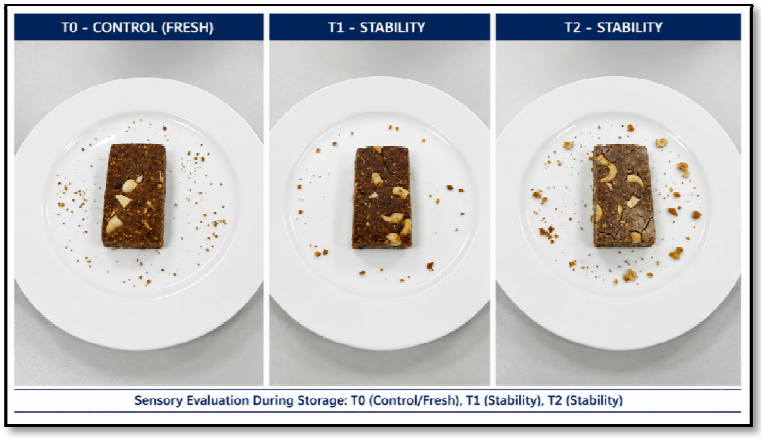


Figure 1. Visual Appearance of Developed Nutritional Bars at Different Storage Intervals (T_0, T_1, and T_2)

D. *Sensory Evaluation*

Sensory evaluation of the developed antioxidant and protein-enriched energy bars was carried out using a panel of semi-trained judges to determine the acceptability of different formulations. The evaluation was performed using a 9-point hedonic scale, where a score of 9 indicated “like extremely” and a score of 1 indicated “dislike extremely.” The sensory attributes assessed included colour, flavour/taste, texture, and overall acceptability. Colour was evaluated based on visual appearance and attractiveness, flavour/taste on palatability and balance of ingredients, texture on mouthfeel and consistency, and overall acceptability on the combined perception of all quality attributes. To minimize bias, the samples were coded and presented randomly to the panelists under controlled conditions. The mean sensory scores obtained were used to identify the most acceptable formulation and to evaluate the effect of incorporating amla pulp, pumpkin peel powder, and pumpkin seed powder on the sensory quality of the developed energy bars.

E. *Cost analysis*

The cost analysis of the developed antioxidant and protein-enriched energy bars was conducted to evaluate the economic feasibility of different treatment combinations.

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The total production cost was calculated based on the prevailing market prices of all raw materials used in each formulation, including oats flour, dates paste, amla pulp, pumpkin peel powder, pumpkin seed powder, honey, peanuts, vegetable oil, and other minor ingredients.

The quantity of each ingredient incorporated into the formulations was considered for estimating the cost per kilogram of the final product. Costs associated with ingredient procurement, processing, mixing, molding, and packaging were also taken into account. The estimated production cost for each treatment was expressed in Indian Rupees (Rs./kg), and a comparative analysis was performed to identify the most cost-effective formulation. This assessment helped determine the economic viability of utilizing fruit and vegetable processing by-products in the development of functional energy bars while maintaining acceptable sensory quality and nutritional benefits.

F. Statistical Analysis

Data obtained from sensory evaluation were expressed as Mean ± Standard Error (SE). Comparative evaluation was performed to identify the most acceptable treatment.

III. RESULTS AND DISCUSSION

A. Sensory Evaluation of Developed Energy Bars

Table 1. Sensory Evaluation of Developed Energy Bars

Treatment Combinations	Colour (Mean ± SE)	Flavour/Taste (Mean ± SE)	Texture (Mean ± SE)	Overall Acceptability (Mean ± SE)
T_0	8.40 ± 0.12^{b}	8.20 ± 0.15^{a}	8.50 ± 0.10^{a}	8.70 ± 0.11^{a}
T_1	8.80 ± 0.10^{a}	8.40 ± 0.12^{a}	8.50 ± 0.14^{a}	8.60 ± 0.09^{a}
T_2	7.40 ± 0.18^{c}	6.40 ± 0.20^{b}	7.30 ± 0.16^{b}	7.30 ± 0.17^{b}

Values are expressed as Mean ± SE. Means within the same column bearing different superscripts (a, b, c) differ significantly at $p \leq 0.05$. Means sharing the same superscript are not significantly different.

The sensory evaluation of the developed antioxidant and protein-enriched energy bars revealed significant differences ($p \leq 0.05$) among the treatment combinations with respect to colour, flavour/taste, texture, and overall acceptability. The incorporation of amla pulp, pumpkin peel powder, and pumpkin seed powder markedly influenced the organoleptic characteristics of the developed products. Among all formulations, T_1 (moderate enrichment) achieved the highest colour score (8.80 ± 0.10), which was significantly higher than T_0 (8.40 ± 0.12) and T_2 (7.40 ± 0.18). The enhanced colour of T_1 may be attributed to the presence of natural pigments, carotenoids, and phenolic compounds present in amla and pumpkin-derived ingredients, which imparted an attractive appearance to the bars. In contrast, the lower colour score observed in T_2 could be due to the excessive incorporation of pumpkin peel powder, resulting in a darker colour that was less preferred by the panelists. Similar findings were reported by Habiba et al. (2021), who observed improved colour acceptability in nutrition bars enriched with pumpkin seed flour at moderate incorporation levels. Likewise, Samakradhamrongthai et al. (2021) reported that incorporation of fruit-based ingredients enhanced the visual appeal of cereal bars, whereas excessive addition adversely affected colour acceptability.

Flavour and taste are among the most critical attributes influencing consumer preference. In the present study, T_1 recorded the highest flavour/taste score (8.40 ± 0.12), which was statistically at par with T_0 (8.20 ± 0.15), while T_2 exhibited a significantly lower score (6.40 ± 0.20). The favourable flavour profile of T_1 may be attributed to the balanced combination of natural sweetness from dates paste and honey with the characteristic fruity flavour of amla and nutty notes from pumpkin seed powder. However, excessive enrichment in T_2 may have introduced increased acidity and slight bitterness due to higher concentrations of amla pulp and pumpkin peel powder, thereby reducing flavour acceptability. These findings are consistent with those reported by Gupta and Bawa (2018), who observed that moderate incorporation of fruit ingredients significantly improved flavour and consumer acceptance of nutrient-rich energy bars. Similarly, Park and Kim (2018) reported superior flavour scores in fruit and nut-based energy bars containing optimal levels of fruit ingredients, while excessive incorporation negatively affected palatability.

Texture evaluation revealed that T_0 (8.50 ± 0.10) and T_1 (8.50 ± 0.14) were statistically similar and significantly superior to T_2 (7.30 ± 0.16). The desirable texture observed in T_1 may be attributed to the combined effects of oats flour, dates paste, and pumpkin seed powder, which contributed to a cohesive structure and pleasant mouthfeel.

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Pumpkin seed powder is known to improve the binding properties and protein content of snack bars, thereby enhancing textural characteristics. In contrast, the reduced texture score of T_2 may be associated with the high fibre content of pumpkin peel powder, which could have produced a denser and coarser product.

Similar observations were reported by Kumar and Sharma (2018), who found that moderate incorporation of fibre-rich ingredients maintained desirable texture in snack bars, whereas excessive inclusion negatively affected mouthfeel. Patel and Desai (2020) also reported that seed fortification improved texture and structural integrity of energy bars when incorporated at optimum levels.

Overall acceptability represents the cumulative perception of all sensory attributes and serves as an important indicator of consumer preference. The overall acceptability scores demonstrated that T_0 (8.70 ± 0.11) and T_1 (8.60 ± 0.09) were statistically similar and significantly higher than T_2 (7.30 ± 0.17). Although the control formulation achieved the highest numerical score, T_1 was considered the most desirable treatment because it provided nearly equivalent sensory acceptance while offering additional nutritional and functional benefits through the incorporation of antioxidant-rich amla pulp and protein-rich pumpkin seed powder. The lower overall acceptability of T_2 indicates that excessive enrichment may compromise consumer preference despite its superior nutritional profile. These findings are in agreement with those reported by Siregar et al. (2024), who observed that moderate incorporation of fruit-based ingredients enhanced overall acceptability of energy bars, while higher levels reduced sensory scores. Similar conclusions were drawn by Sharma and Singh (2016), who reported that optimum incorporation of functional ingredients improved both nutritional quality and consumer acceptance of traditional energy bars.

The results of the present study clearly indicate that moderate incorporation of amla pulp, pumpkin peel powder, and pumpkin seed powder can significantly improve the nutritional value of energy bars without adversely affecting sensory quality. The T_1 formulation emerged as the most suitable treatment, providing an ideal balance between functionality, nutritional enhancement, and consumer acceptability. These findings further support the growing evidence that fruit and vegetable processing by-products can be effectively utilized in functional food development, contributing to both sustainable food production and improved public health.

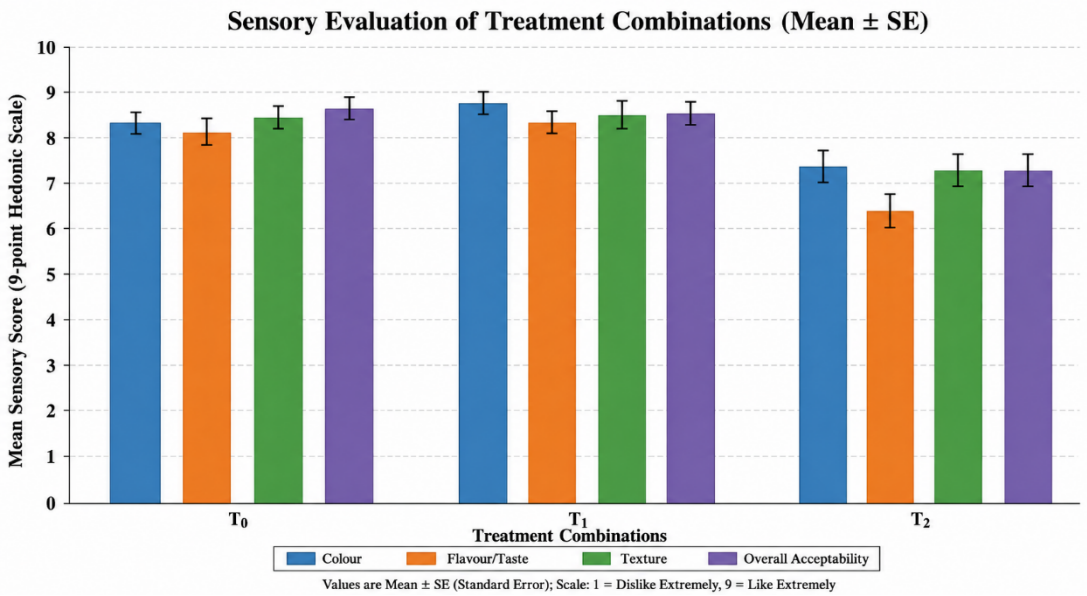


Figure 2. Sensory Evaluation of Developed Product Treatments (T_0–T_2) for Colour, Flavour/Taste, Texture, and Overall Acceptability (Mean ± SE)

B. Cost Analysis

Table 2. Estimated Cost of Production of Energy Bars

Treatment	Cost (Rs./kg)
T_0	180.00
T_1	175.00
T_2	172.00

The production cost decreased progressively with increasing levels of by-product incorporation. Pumpkin peel powder and amla pulp served as economical functional ingredients capable of replacing more expensive conventional components. Although T_2 showed the lowest cost, sensory evaluation identified T_1 as the most commercially viable formulation due to its superior acceptability.

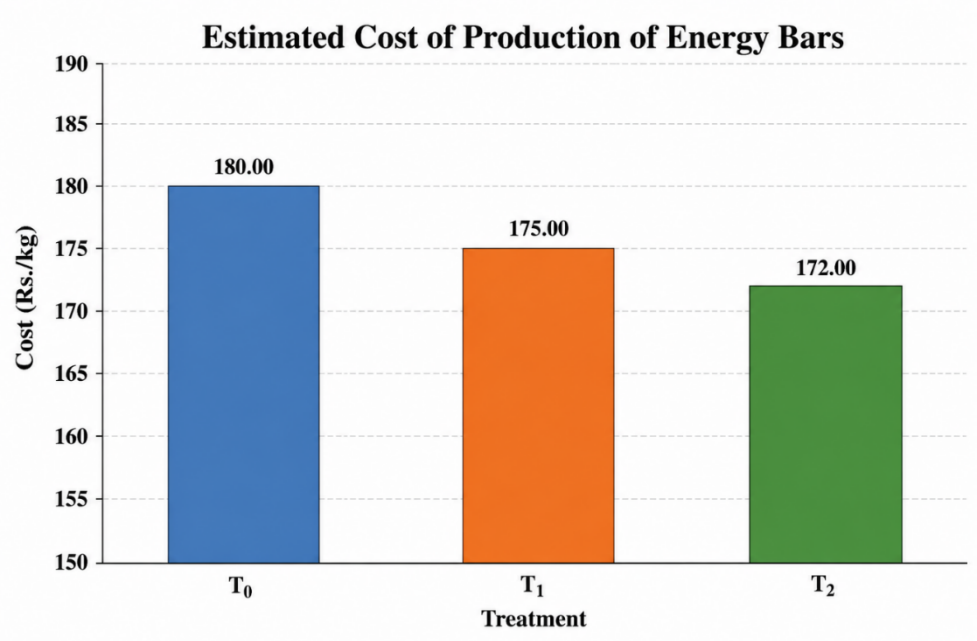


Figure 3. Estimated Cost of Production of Developed Energy Bars (Rs./kg) Across Different Treatment Combinations (T_0–T_2)

IV. CONCLUSION

The present investigation successfully developed antioxidant and protein-enriched energy bars using amla pulp, pumpkin peel powder, and pumpkin seed powder. Sensory evaluation demonstrated that the moderately enriched formulation (T_1) achieved the highest overall consumer acceptability while providing enhanced nutritional benefits. The incorporation of fruit and vegetable processing by-products improved product functionality and reduced production costs. The study highlights the potential of underutilized food resources in the development of sustainable, affordable, and health-promoting snack products. Future studies should focus on detailed nutritional profiling, antioxidant analysis, shelf-life evaluation, and consumer market acceptance to facilitate commercialization.

V. ACKNOWLEDGEMENTS

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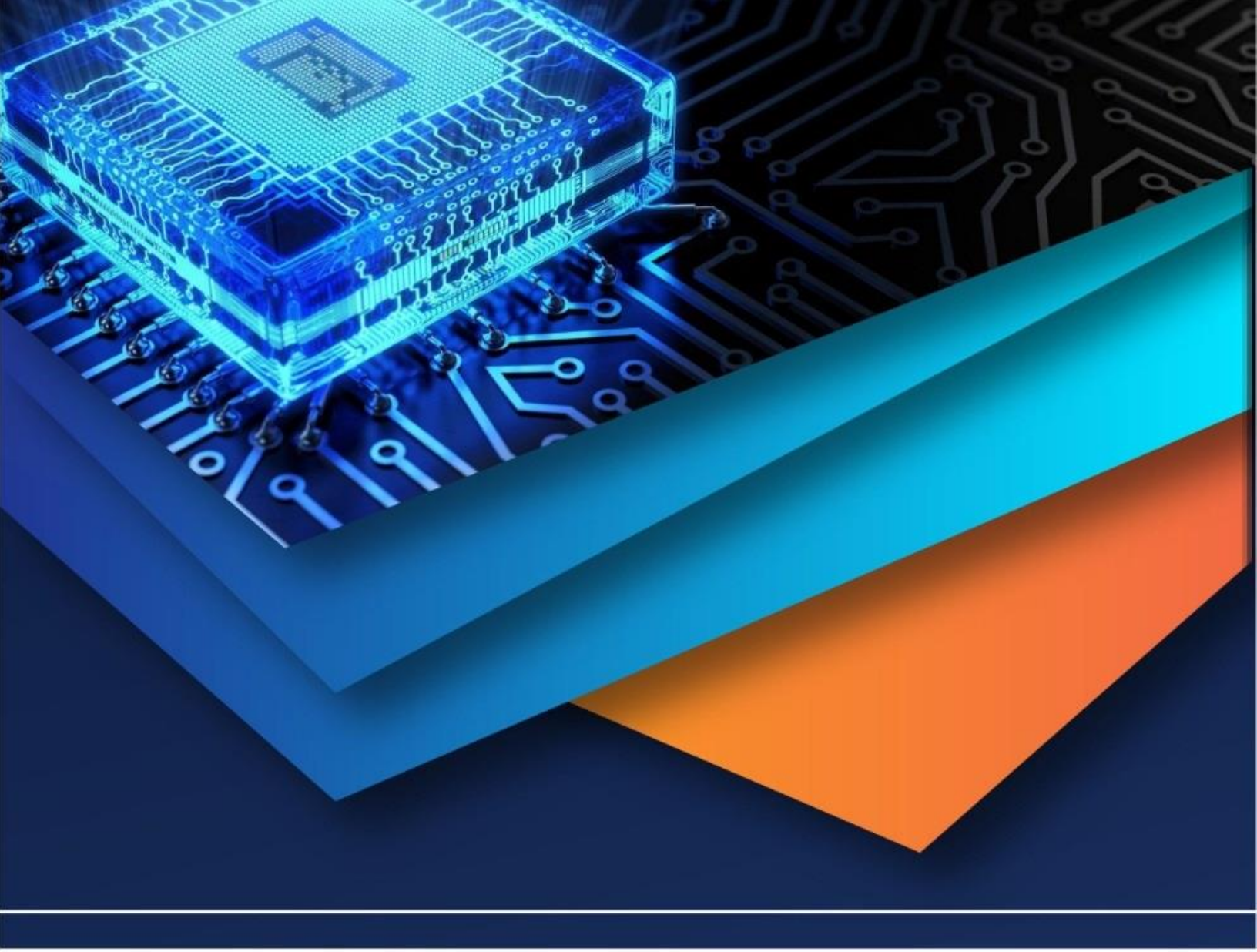
CONFLICT OF INTEREST

The authors declare no conflict of interest.

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