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Properties of Fruits By-Products in the Development of Biodegradable Films - A Review

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Abstract: Millions of tons of fruit wastes are generated globally from spoilage and industrial by-products. These wastes should be utilized in order to increase their value.
This goal can be accomplished by incorporating fruit waste into polymeric materials. The fruit waste includes peels/skin, puree, seeds etc.
These wastes are generally thrown away in form of leftover and used as feed or composted, but they are a great source of bioactive compounds like polyphenols, vitamins or minerals.
The utilized fruit waste provides a sustainable packaging material. This review summarizes about the fruit waste produced during industrial processing and recent researches to reutilize the fruit waste in order to enhance the physical, chemical, antioxidant and antimicrobial properties in polymeric matrices.
Keywords: Fruit Waste, Biodegradable Film, Bioactive Compound, By-Product properties.

I. INTRODUCTION

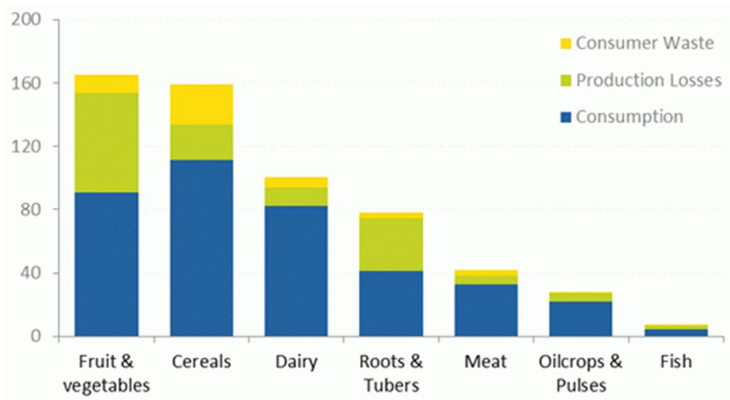
Every year there is a constantly growing rate of food lost and wasted all around the globe. According to FAO analysis [1], 1.3 billion of food are wasted annually.

Food waste has been defined as "food losses of quality and quantity through the process of the supply chain taking place at production, post-harvest and processing stages [2]. Food waste, or the residues of food processing industries, is increasingly viewed as a resource to be diverted from landfilling.

In a circular economy, where food waste management is developed sustainably, food waste has great potential for recovery into energy, fuel, natural nutrients, or biomaterials through a set of technologies [3]. Food industry produces large volumes of both solid and liquid wastes, which result from the production, preparation and consumption of food [4]. These wastes cause increasing potential disposal and severe pollution problems and represent loss of valuable biomass.

Therefore, these wastes can be utilized to in order to reduce the pollution problems and to increase the values. The waste obtained from fruits and processing industry is extremely diverse due to the use of wide variety of fruits and vegetables, the broad range of processes and the multiplicity of the product [5]. As an example, tropical and subtropical fruits processing have considerably higher ratios of by-products than the temperate fruits. Due to increasing production and processing of fruits and vegetables, disposal represents a growing problem since the plant material is usually prone to microbial spoilage, thus limiting further exploitation. On the other hand, costs of drying, storage and shipment of by-products are economically limiting factors. Therefore, agro-industrial waste is often utilized as feed or as fertilizer [6].

The most common fruits consumed worldwide are apples, grapes, and exotic fruits typical for the cultivation region. The processing of plant foods results in the production of by-products that are rich sources of bioactive compounds, including phenolic compounds [7]. The antioxidant compounds from waste product of food industry could be used for increasing the stability of foods by preventing lipid peroxidation and also for protecting oxidative damage in living systems by scavenging oxygen free radicals [8]. Studies have shown that the residues of certain fruits can present a higher antioxidant activity than the pulp. The objective of review is to highlight the properties of fruit waste in order to incorporate in a biodegradable film.



Note: Consumption is food that is eaten. Production losses occur during harvest, storage, handling, transportation, processing, distribution and as spoilage at retail level. Consumer waste is edible food discarded at household level. Total global food supply is around 580 kg per person,380 kg of which is consumed,140 kg is lost and 50 kg is wasted.

Figure 1: Food Wastages Source: Gustavssan *et al.*,(2011) ,FAO

II. FRUIT BY-PRODUCTS

Apple by-products represent 25–30% of the weight of the original fresh fruit. These residues are an important source of phenolic compounds, like hydroxycinnamic acid derivates and flavonoids [9,10]. According to the experimental findings of Urbina *et al.*, [9], apple by-products could be used in a completely renewable active packaging. Specifically, the authors developed a bacterial cellulose-based nano-papers then coated with a medium-chain-length poly-hydroxy-alkanoate layer (mcl-PHA). Subsequently, extracts from cider by-products were incorporated at different percentages Foods 2020, 9, 857 5 of 19 (1%, 3% and 5% respect to the PHA) to develop an antioxidant film with optimal free radical scavenging capacity. As regard grape by-products, around 20% of whole grapes are generally rejected after the wine making process, even though these by-products are very rich in flavonoids and phenols (more that 70% are found in the skin) [11-13]. Interesting results were found in the study of Kurek *et al.*, [11] who used two different bio-resources (red grape skin pomace and blueberry extracts) to develop a new active packaging with antioxidant properties. The extracts obtained by microwave-assisted extraction were incorporated into chitosan and carboxymethyl cellulose film, respectively. The films added with red grape skin extract exerted greater antioxidant activity than those enriched with blueberry extract, although an inverse correlation of polyphenol content and antioxidant activity was highlighted. Shahbazi [12] studied the potential application of grape seed extract (GSE 1% w/v) alone and in combination with an essential oil (ZEO, Ziziphora clinopodioides) in chitosan and gelatin films. The author observed that, in both films, the highest total phenolic content was found with the combination of both active compounds. Ferreira et al. [13] evaluated the effect of three grape pomace extracts (water extract 0.15%, wax extract 0.15–0.3% and oil extract 0.3–0.75%) into chitosan film. The study showed that the different nature of the extracts improved the antioxidant activity, also influencing the final film properties. Specifically, the wax extracts allowed obtaining films with better mechanical properties, whereas the lipid extracts reduced the solubility in water and led to slight change in the mechanical properties. Mango by-products (kernel and peel) were also used in food packaging. Mango is the third most exported exotic fruit and its by-products are generally used for bio-refineries. Every year, about one million tons of mango seeds are eliminated by the industries without any other application, knowing that the seeds make up 20–60% of the whole fruit. An excellent use is reported in the study conducted by Melo et al. [14]. The researchers used three chemical fractions extracted from mango kernels (kernel starch, kernel fat and kernel phenolic extract) to develop active films. The authors highlighted that active systems exerted antioxidant capacity, UV absorbing and good barrier properties but reduced tensile properties and transparency. The possibility of conferring antioxidant activity to packaging by adding mango kernel extract, was also studied by Adilah *et al*. [15]. They observed that the incorporation of the extract into two biopolymers (soy protein isolate and fish gelatin) improved the film antioxidant activity. The authors justified the better results of the soy protein-based film with the globular structure of the raw material and the likely lower protein-phenol interaction compared to the linear structure of fish gelatin film. In a more recent study Adilah et al., [15] assessed the stability of a soy protein-based film enriched with the same mango kernel extract during 90 days of storage at different temperatures (25, 4 and −18 ◦C). The total phenolic content of film stored at room temperature was around 26 to 50% higher than films at 4 and −18 ◦C, respectively.

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Regarding the antioxidant activity, it remained stable at 25 ◦C, while it slight decreased at refrigeration and freezing temperature. These results can be associated not only to the loss of extract during storage but also to possible change in the film protein structure. Mango leaf extract was less explored, even if it is rich in gallic acid, glucosides and phenolic compounds [16]. The study conducted by Rambabu *et al*. [17] evaluated the incorporation of mango leave extract (1%, 3% and 5%) into chitosan, and then the application of the active system to cashews. As expected, the total phenolic content of films increased as the extract increased. Peroxide values monitored for 28 days highlighted that 3% and 5% enriched films better inhibited the oxidation process of cashews. Pomegranate by-products, such as peel, seed and pomace, were re-used as derivates from pomegranate juice and jam industry. High scavenging properties of free radicals, antimicrobial and anti-mutagenic properties of pomegranate peel extract increased the interest in this by-product, thus leading to develop active films . Hanani *et al*. [18] used pomegranate, papaya and jackfruit peel in form of powder to develop a bi-layer film made up of fish gelatin and polyethylene (PE). In particular, the three by-products were added (0–9% w/v) separately to the fish gelatin solution, and then, each active film was cast onto the PE layer to form a bi-layer matrix. The comparison among the three active kinds of packaging showed that pomegranate peel powder was the most interesting by-product because it has a high phenolic content and gave the films a good antioxidant activity.

III. CHARACTERISTICS OF FRUIT WASTE

A. Bioactive Compounds

Bioactive compounds are defined as substances with biological activity and are able to modulate metabolic processes resulting in the promotion of better health conditions. The benefits exhibited by these compounds include antioxidant activity, inhibition or induction of enzymes, inhibition of receptor activities, and induction and inhibition of gene expression.[19]

B. Dietary Fibre From Fruit Waste

Apple peel had higher dietary fiber content (0.91% FW) than the pulp. The percentage of insoluble and soluble dietary fibers was 0.46% FW and 0.43% FW, respectively. Apple pomace is a waste material from apple juice processing and contains significant amounts of dietary fiber.[20]

Grapes pomace was found to be a rich source of dietary fibers, namely, hemicelluloses, cellulose, and small proportions of pectins. he red grape cultivar "Tempranillo" had the highest dietary fiber content in the pomace (36.90 g/100 g FW), stem (34.80 g/100 g FW), and fruit (5.10 g/100 g FW). "Manto Negro" red grape pomace TDF content was 77.20% DM, and soluble fibers were lower (3.77% DM) than the insoluble fibers (73.50% DM) [21]

Mango by-products have been shown to possess high amounts of dietary fibers. Mango peel contains 51.2% DM of TDFs (32% DM insoluble fibers and 19% DM soluble fibers). [22]

Table 1: Total (TDF), insoluble (IDF), and soluble (SDF) dietary fibre contents in the waste of different fruits Source Farhath Khanum *et al.* 2010

Commodities	Total dietary fibre	Insoluble	soluble
Apple	2.0	1.8	0.2
Kiwi	3.39	2.61	0.80
Mango	1.80	1.06	0.74
Pineapple	1.20	1.10	0.10
Pomegranate	0.60	0.49	0.11
Watermelon	0.50	0.30	0.20
Grapes	1.2	0.7	0.5
Plums	1.6	0.7	0.9
Strawberry	2.2	1.31	0.9
bananas	1.7	1.2	0.5
Peach	1.9	1.0	0.9
pear	3.0	2.0	1.0
Oranges	1.8	0.7	1.1

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C. Phenolic compounds

Phenolic compounds are the plant secondary metabolites responsible sensory characteristics and contribute to the nutritional quality of fruits. Phenolic compounds are among the largest classes of bioactive compounds with diverse and important biological functions. Polyphenolic compounds are classified into various classes such as flavonoids (subclasses: flavonols, flavanones, flavones, flavanonols, isoflavones, flavanols, and anthocyanidins), tannnis, stilbenes, phenolic acids, and lignans. The rind, peel, and seeds of fruits and vegetables possess high amounts of phenolic compounds. The citrus industry produces major amounts of seeds and peel residues, which constitute about 50% of the total fruit [23]. Citrus waste is a rich source of phenolic compounds because citrus peel contains a higher quantity of polyphenols in comparison with the edible part of the fruit. amounts of total phenolics in the peels of apples, peaches, and pears compared to peeled fruits. It was reported that banana pulp (*Musa cavendish*) contains 232 mg/100 g DM of phenolic compounds, which is only about 25% of that found in the peel. Along with phenolic compounds, higher amounts of catecholamines, dopamine, and L-dopa were also found in banana peels. Pomegranate peels contain 249.4 mg/g phenolic compounds, while the pulp contains 24.4 mg/g.

Fruits	Fruit waste	Phenolic compounds present in fruit waste
Grapes	Pomace	Catechins, anthocyanins, stilbenes, flavonol glycosides
Grapes	Skin	Catechin, epicatechin, epigallocatechin, picatechin gallate
Kiwifruit	Peel	Caffeic acid, protocatechuic acid, p-coumaric acid
Mango	Seed kernel	Gallates, gallotannins, gallic acid, ellagic acid
Mango	Peel	Flavonol glycosides
Purple star apple	Peel	Ferulic, sinapic caffeic, gallic, myricetin, ellagic
Quince	Leaves	(+) Catechin, procyanidin B1, procyanidin B2, procyanidin C1, 4-*O*-caffeoylquinic acid, kaempferol-3-*O*-rutinoside, kaempferol-3-*O*-glucoside, quercetin-3-*O*-galactoside, quercetin-3-*O*-rutinoside
Apple	Pomace	Hydroxycinnamates, phloretin glycosides, quercetin glycosides, catechins, procyanidins

Table 2: Phenolic Compounds of Fruit Waste

IV. ANTIMICROBIAL PROPERTIES IN FRUIT WASTE

Most bioactive compounds extracted from by-products are able to affect microbial and fungal growth. Fruit by product adopted as peel or skin powder and as peel, skin or leaf extract to develop films with antimicrobial properties, tested against spoilage and pathogenic microorganisms. For example; apple skin target microorganisms such as E. coli, S.enterica and L.monocytogenes and then it is extracted to incorporate in active packaging i.e, chitosan edible films. This helps to enchance the anti-microbial properties of packaging film and used for packing perishable foods items.

Fruit by product	Active packaging	Target microorganisms
Apple skin	Chitosan edible film	E. coli, S. enterica and L. monocytogenes [24]
Apple skin (powder, extract)	Composite films ASP/CMC	L. monocytogenes, S. aureus, S. enterica and S. Flexner [24]
Apricot kernel extract	Chitosan film	E. coli and Bacillus subtilis [25]
Blueberry leaf extract	Chitosan coating	S. aureus, L. monocytogenes, S. typhimurium, E. coli and fungi [83]
Grape seed extract	Chitosan film Chitosan film and carvacrol	E.coli, L. monocytogenes, S. aureus and P. aeruginosa Mesophilic and psychrophilic bacteria and Pseudomonas spp [24]
Grapefruit seed extract	Coated wrapping paper Biopolymer carrageenan Layer-by-layer coating with alginate, chitosan Chitosan films LDPE and PLA	L. monocytogenes and E.coli, Gram-positive and Gram-negative food-borne pathogens,Mesophilic and psychrotrophic bacteria,Fungi LDPE and PLA, E. coli and L. monocytogenes[24]
Pomegranate peel extract	Casein-based film Chitosan coating, Zein-based film	S. aureus, E. coli Total aerobic bacteria, Pseudomonas spp., P. digitatum,E. coli, P. perfringens, M. luteus, E. faecalis, S. aureus, P. vulgaris and s.typhii [26]
Pomegranate peel powder	Fish Gelatin film Starch-based film	S. aureus, L. monocytogenes and E. coli [26]

Table 3: Anti-Microbial packaging with fruit by products

V. PHYSICAL AND MECHANICAL PROPERTIES OF FRUIT BY PRODUCTS:

The requirements of films and coatings in terms of physical and mechanical properties depend on characteristics of the food that is to be protected. Therefore, components such as crosslinkers and nano-reinforcements, to be added to the polymeric matrix to improve barrier, tensile and water resistance properties are of striking importance. As can be seen from Table 3, fruit by-products are abundantly investigated for this aim. In particular, Priyadarshi *et al.*, [25] asserted that the incorporation of apricot kernel essential oil into chitosan film improved both physical and chemical properties. The authors observed that formation of covalent bonds between chitosan and functional groups of apricot kernel oil and the creation of a bilayer (chitosan/apricot kernel oil) reduced moisture content and water absorption of the active film compared to pure chitosan. Furthermore, the addition of apricot kernel oil improved the mechanical properties (increase in tensile strength of about 94%), reduced film solubility in water and improved the water vapor barrier properties (approximately 41%), due to the hydrophobic components in the polymeric structure.

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Fruit by-product	Packaging system	Physical and Mechanical properties
Apricot kernel oil (AKo)	Chitosan film with AKo (1:0, 1:0.125, 1:0.25, 1:0.5 and 1:1 w/v).	Essential oil improved TS* and WVB**, and reduced film solubility (from 18.42 to 4.76%). [27]
Blueberry waste (BW)	Cassava starch film with BW powder (4, 8 and 12 wt%)	BW decreased SI** (pH 2.5, 7.0 and 10.0) and promoted UV protection. [28]
Citrus peel and leaves	Kraft paper + peel:leaf extract (2:0, 2:1, 3:0)	Peel: leaf extract (2:1) increased WVB** and O2B* [27]
Grape seed (GSE)	Chitosan and gelatin films with GSE (1% v/w) and Ziziphora clinopodioides essential oil (ZEO)	1% GSE + 1% ZEO decreased TS*, PF*, PD* and SI**; increased WVB**. [29]
Grape seed (GSE) + Pomegranate peel (PPE)	Surimi edible films with GSE + PPE (0%, 2%, 4% and 6%).	6% PPE improved TS*; 6% GSE increased WVB** and both reduced light transmission [30]
Mango peel and kernel (MKE)	Edible mango peel coating with MKE (0.078 g/L).	MKE reduced WVB** and film solubility (from 60.24 to 52.56%). [27]
Mango peel extract (MPE)	Fish gelatin film with MPE (1%, 3% and 5%).	MPE improved TS* (from 7.65 to 15.78 MPa) and reduced solubility from 40% to 20% [30]
Mango kernel starch	Composite film (kernel starch and guar/xanthan gum 10%, 20% and 30%).	The different % of gums increased TS and O2B**, but decreased the film solubility and WVB* [30]
Pomegranate peel extract (PPE)	Zein film with PPE (0, 25, 50, and 75 mg/mL of film forming solution).	PPE improved TS* and WVB**, increased film solubility from 6.166% (control) to 18.29% (75 mg PPE). [31]

Table 4: Physical and Mechanical Properties of Fruit Waste

VI. APPLICATION OF FRUIT BY-PRODUCT IN DEVELOPMENT OFBIODEGRADABLE FILM:

The different application has been reported by Luchese *et al.*, [31], who developed cassava starch film, by compression molding, to valorize by-products from blueberry juice processing (powder 4, 8 and 12 wt%).Shahbazi [10] observed that chitosan and gelatin films enriched with red grape seed extract (GSE) showed lower mechanical properties (tensile strength—TS, puncture force—PF and puncture deformation—PD) than ZEO-formulated films (Ziziphora clinopodioides essential oil). Recently, Munir *et al.*, [32] noted that both the nature of the extract and its final concentration may have different influence on film properties. In particular, pomegranate peel extract (2%, 4%, 6% PPE) improved tensile strength of Surimi-based edible films compared to GSE at the same concentrations. By-products from mango processing industry are characterized by high content of polysaccharides, in particular in the peel, which represents about 7–24% of the whole fruit weight. Mango peel (powder 1.09% by weight) was used by Torres-Leon *et al.*, [33] to formulate an edible film with and without addition of antioxidant extract from fruit kernel. The addition of mango kernel extract increased the film water vapor permeability, while the presence of carotenoids and anthocyanins in the mango peel conferred to the film good barrier to radiation in the light spectrum (600 nm). Nawab *et al.* ,[34] evaluated the effect of guar and xanthan gums (10%, 20% and 30%) on the properties of mango kernel starch films. The mango kernel is a great source of starch, about 56% on dry basis.

Figure 2: Sustainable use of fruit by-product to enhance the food packaging performance

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VII. CONCLUSION

The reutilization of fruit by-product (peels, puree, pomace, seeds, etc.) has significant role producing materials such as packaging material etc. These fruits waste produce huge amount of food residues, this creates problem during disposal . This problem is reduced by incorporating into polymeric material. These by-products as source of bioactive compounds (polysaccharides, fibres, phenolic compounds, vitamins, minerals, etc.) . It is also acknowledged that environmental impact generated by the petroleum-derived polymers paves the route for the development of greener alternatives and demands for replacing conventional plastics by renewable and biodegradable materials. By incorporating fruit wastes in packaging film enhance the film properties.

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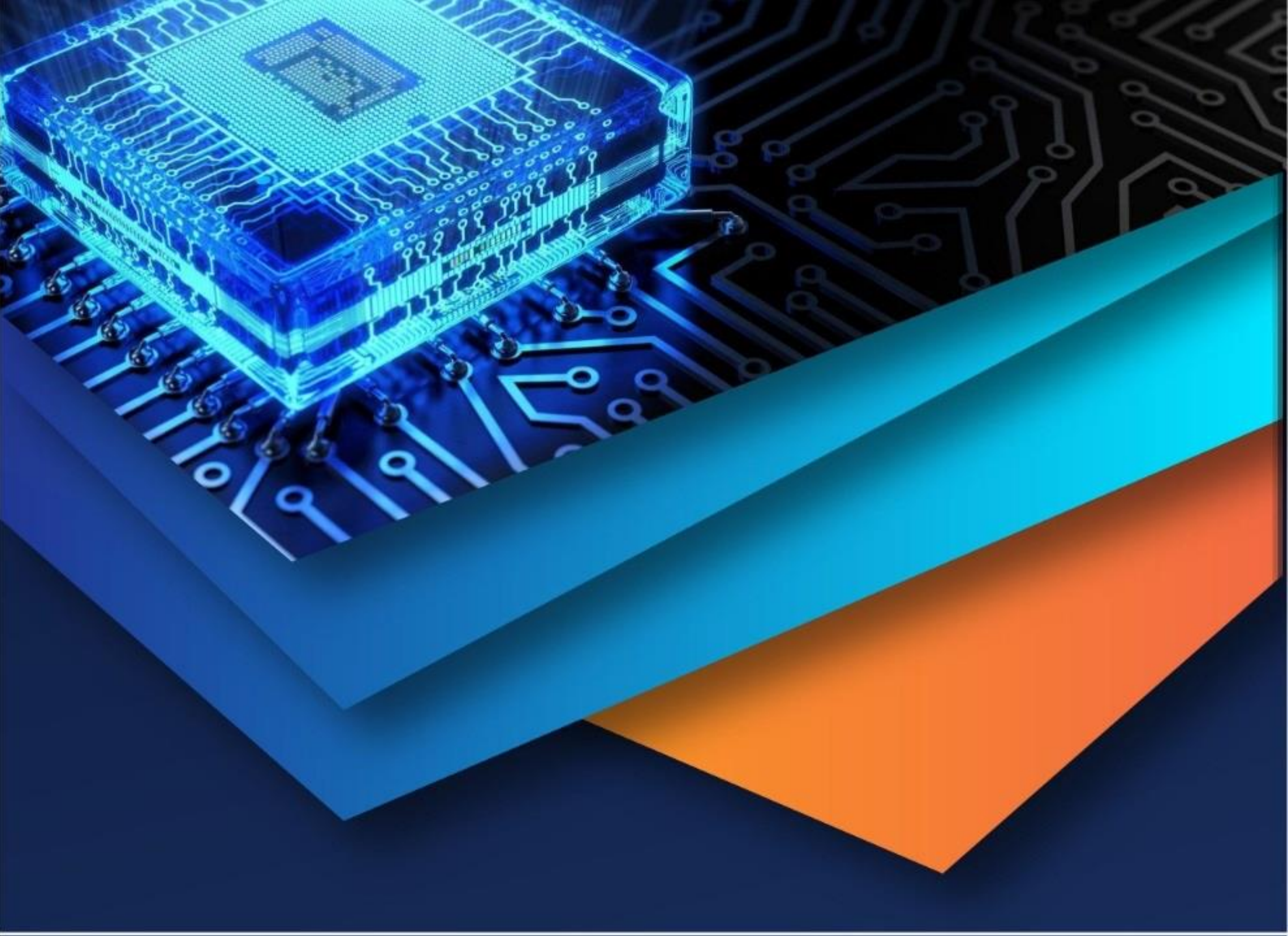

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