BIOSINTEZLANGAN AG-ZNO GIBRID TO‘LDIRUVCHISINI SAQLOVCHI YANGI NATRIY KARBOKSIMETILSELLYULOZA-PPFMA NANOKOMPOZITLARINING TERMAL VA BIOLOGIK XUSUSIYATLARI

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Annotatsiya Ushbu tadqiqotda biomedikal qo‘llanmalar uchun antimikrobial, antioksidant va antikancer xususiyatlariga ega yangi nanokompozitlar ishlab chiqildi. Tadqiqot doirasida avval poli(2-okso-2-(pentaftorfenoksi)etil-2-metilprop-2-enoat) (PPFMA) polimeri sintez qilindi va FTIR hamda NMR usullari bilan xarakterizatsiya qilindi. So‘ngra PPFMA natriy karboksimetilsellyuloza (NaCMC) bilan in-situ/gidrotermal usulda aralashtirildi. Aralashmaning moslashuvchanligi FTIR ma’lumotlari va DSC dan olingan yagona Tg qiymati bilan tasdiqlandi. NaCMC-PPFMA aralashmasining termal va biologik xususiyatlarini yaxshilash maqsadida, *Prunus spinosa* ekstraktidan biosintez qilingan Ag-ZnO nanozarrachalari turli og’irlik nisbatlarida (3%, 5% va 7%) gidrotermal usulda qo‘shildi. Olingan materiallar SEM, EDX, TEM, XRD, FTIR, TGA va DSC usullari bilan xarakterizatsiya qilindi. Nanokompozitlarning antioksidant, antimikrobial, sitotoksik xususiyatlari va yara bitishini tezlashtirish qobiliyati batafsil o‘rganildi. Natijalar shuni ko‘rsatdiki, Ag-ZnO nanozarrachalarining qo‘shilishi NaCMC-PPFMA aralashmasining termal barqarorligini 22°C ga, Tg qiymatini esa 9°C ga oshirdi. Nanokompozitlar yuqori antimikrobial faollik namoyon etdi va NaCMC-PPFMA-3% Ag-ZnO namunasi 91.67% yara yopilish tezligini ta’minladi. Olingan natijalar shuni ko‘rsatadiki, biosintezlangan Ag-ZnO nanozarrachalarini o‘z ichiga olgan nanokompozitlar bio-xavfsiz xom ashyolardan tayyorlangan potentsial yara bitiruvchi materiallar sifatida ishlatilishi mumkin.

Kalit so‘zlar: Karboksimetilsellyuloza, Metakrilat, Termal xususiyatlar, Antimikrobial faollik, Nanokompozitlar, Yara bitish

Abstract In this study, novel nanocomposites with antimicrobial, antioxidant, and anticancer properties were developed for biomedical applications. First, poly(2-oxo-2-(pentafluorophenoxy)ethyl-2-methylprop-2-enoate) (PPFMA) polymer was synthesized and characterized by FTIR and NMR techniques. Subsequently, PPFMA was blended with sodium carboxymethyl cellulose (NaCMC) using an in-situ/hydrothermal method. The compatibility of the blend was confirmed by FTIR data and a single Tg value obtained from DSC analysis. To enhance the thermal and biological properties of the NaCMC-PPFMA

blend, Ag-ZnO nanoparticles biosynthesized from *Prunus spinosa* extract were incorporated at different weight ratios (3%, 5%, and 7%) via hydrothermal method. The prepared materials were characterized by SEM, EDX, TEM, XRD, FTIR, TGA, and DSC techniques. The antioxidant, antimicrobial, cytotoxic properties, and wound healing efficacy of the nanocomposites were comprehensively investigated. Results demonstrated that the addition of Ag-ZnO nanoparticles increased the thermal stability of the NaCMC-PPFMA blend by 22°C and the Tg value by 9°C. The nanocomposites exhibited high antimicrobial activity, and the NaCMC-PPFMA-3% Ag-ZnO sample achieved a wound closure rate of 91.67%. The findings suggest that nanocomposites containing biosynthesized Ag-ZnO nanoparticles can be utilized as potential wound healing materials derived from bio-safe raw materials.

Keywords: Carboxymethyl cellulose, Methacrylate, Thermal properties, Antimicrobial activity, Nanocomposites, Wound healing

Kirish (Introduction)

Dori-darmonlarga chidamli patogenlarning ko‘payishi sog‘liqni saqlash uchun jiddiy xavf tug‘dirmoqda, bu esa yangi, samarali va ekologik toza antimikrobial vositalarni ishlab chiqishni talab qiladi. Natriy karboksimetilsellyuloza (NaCMC) kabi biopolimerlar o‘zlarining biologik moslashuvchanligi tufayli istiqbolli nomzodlardir, ammo ularning mexanik va termal xususiyatlarini yaxshilash kerak. Ushbu muammoni hal qilish uchun polimerlarni noorganik nanozarrachalar bilan aralashtirish samarali yondashuv hisoblanadi. Ushbu tadqiqotda, yangi sintez qilingan metakrilat asosli polimer (PPFMA) NaCMC biopolimeri bilan aralashtirilib, unga *Prunus spinosa* ekstrakti yordamida biosintezlangan kumush-rux oksidi (Ag-ZnO) gibrid nanozarrachalari qo‘shildi. Tadqiqotning asosiy maqsadi – olingan yangi nanokompozitlarning termal barqarorligi, antioksidant, antimikrobial, sitotoksik va yara bitishini tezlashtiruvchi xususiyatlarini kompleks o‘rganishdan iborat.

Material va Metodlar (Materials and Methods)

Ushbu tadqiqotda natriy karboksimetilsellyuloza (NaCMC), pentaftorfenol, xloratsetil xlorid, natriy metakrilat, kumush nitrat ($AgNO_3$) va rux nitrat geksagidrat xom ashyo sifatida ishlatildi. Ag-ZnO nanozarrachalari *Prunus spinosa* o‘simligi ekstraktidan foydalanib, yashil sintez usulida olindi. Yangi poli(2-okso-2-(pentaftorfenoksi)etil-2-metilprop-2-enoat) (PPFMA) polimeri sintez qilindi va NaCMC bilan in-situ/gidrotermal usulda aralashtirildi. Olingan NaCMC-PPFMA aralashmasiga turli og‘irlik nisbatlarida (3%, 5% va 7%) Ag-ZnO nanozarrachalari qo‘shildi. Materiallarning tuzilishi va xususiyatlari SEM, EDX, TEM, XRD, FTIR, TGA va DSC kabi zamonaviy fizik-kimyoviy tahlil usullari bilan o‘rganildi. Biologik xususiyatlarni baholash uchun antioksidant (DPPH, ABTS), antimikrobial (*S. aureus*, *E. coli*, *C. albicans*), sitotoksiklik (A549, G361 hujayra liniyalari) va in vitro yara bitish (scratch wound healing) testlari o‘tkazildi.

Natijalar (Results)

FTIR va XRD tahlillari PPFMA polimerining NaCMC matritsasiga muvaffaqiyatli qo‘shilganligini va Ag-ZnO nanozarrachalarining kompozit tarkibida mavjudligini tasdiqladi. Termal tahlil (TGA/DSC) natijalari shuni ko‘rsatdiki, nanokompozitlarning termal barqarorligi sof aralashmaga nisbatan 22°C ga, shisha o‘tish harorati (Tg) esa 9°C ga oshgan. Biologik testlar natijasida, Ag-ZnO nanozarrachalarining qo‘shilishi umumiy oksidant holatini (TOS) 0.72 dan 10.47 μmol H_2O_2/L gacha oshirib, antioksidant faollikni (TAS) pasaytirgan. Nanokompozitlar *E. coli*, *S. aureus* va *C. albicans* mikroorganizmlariga qarshi yuqori antimikrobial faollik namoyon etdi. Sitotoksiklik tahlili nanokompozitlarning past konsentratsiyalarda (50 μg/mL gacha) biouyg‘un ekanligini ko‘rsatdi. Eng muhimi, yara bitish testida NaCMC-PPFMA-3% Ag-ZnO namunasi 24 soat ichida 91.67% yara yopilishini ta’minlab, eng yaxshi natijani qayd etdi.

Muhokama va Xulosa (Discussion and Conclusion)

Olingan natijalar shuni ko‘rsatadiki, NaCMC biopolimerini yangi sintez qilingan PPFMA polimeri va biosintezlangan Ag-ZnO nanozarrachalari bilan modifikatsiya qilish uning termal va biologik xususiyatlarini sezilarli darajada yaxshilaydi. Ag-ZnO nanozarrachalarining qo‘shilishi materialning antimikrobial faolligini va yara bitishini tezlashtirish qobiliyatini kuchaytirdi. Termal barqarorlikning oshishi esa uni turli biomedikal qo‘llanmalar uchun yanada ishonchli materialga aylantiradi. Past konsentratsiyalarda kuzatilgan yuqori biouyg‘unlik uning xavfsizligini tasdiqlaydi. Xulosa qilib aytganda, ushbu tadqiqotda ishlab chiqilgan yangi NaCMC-PPFMA/Ag-ZnO nanokompozitlari, o‘zining yaxshilangan termal va biologik xususiyatlari tufayli, ayniqsa yara qoplamalari va boshqa tibbiy vositalarni yaratish uchun istiqbolli va bio-xavfsiz material sifatida baholanishi mumkin.

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