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Microencapsulation of Spray Dried Resveratrol Emulsion Using Sodium Caseinate-Maltodextrin Conjugate

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Abstract

Resveratrol (RSV) has been linked to a wide range of biological activities, particularly anti-oxidant, antibacterial, anti-inflammatory, and anti-carcinogenic characteristics. However, because of limitations such as chemical deterioration happen during storage (UV light and oxygen), low aqueous solubility, and oral bioavailability, this study used an emulsion-based system with sodium caseinate-maltodextrin (SC-MD) conjugate by Maillard reaction as coating materials to increase RSV aqueous solubility. The characterization of microencapsulated RSV emulsion spray-dried powder was done. Conjugate and casein microencapsulated RSV spray-dried powder showed 76.41 and 54.61% encapsulation efficiency, 7 and 6.5 mm of average diameter, respectively. The composition of spray-dried microencapsulated RSV emulsion with conjugate was found to be 14.2% moisture, 85.78% total solids, 38.20% protein, 7.81% fat, 0.83% ash, and 38.2% carbohydrate. As a result, microencapsulated RSV spray-dried powder with a SC-MD conjugate improves the stability of RSV for providing the polyphenolic health advantages of RSV.

Keywords

Resveratrol, Conjugate, Microemulsion, Spray drying, Encapsulation efficiency

Introduction

Resveratrol (RSV) (trans-3,5,4'-trihydroxystilbene; $C_{14}H_{12}O_3$), a polyphenol belongs to stilbens family having molecular weight of 228.25 g mol^{-1}, and a high solubility in ethanol up to 50 mg/ml, is a triphenolic phytoalexin [1-3]. Red grape and peanut skins were the predominant sources of RSV. Research has revealed that RSV has several health benefits properties like antioxidant, anti-inflammatory, protection from infection and lachomia, cardioprotective, anti-obesity, neuroprotective, antiviral, anticarcinogenic brain as well as heath protective effect [4, 5].

In addition to its health beneficial, RSV can be used as a nutraceutical compound in the food industry, despite its limitations, which include low dispensability in aqueous solution, chemical degradation from UV light and oxygen during storage, and low oral bioavailability, as well as degradation under pancreatic conditions. To address this issue, RSV was encapsulated using a variety of techniques including, fluidized-bed coating, coacervation, liposome entrapment, and spray drying [6], emulsion-based, niosomes, biopolymer particles, inclusion complexes [1, 7]. The RSV can be synthesized using a variety of oil carriers and emulsifiers before being encapsulated using emulsion methods. Donsi et al. revealed that RSV (0.01%) can be effectively dissolved in peanut oil after testing a variety of

carrier oils [8]. Protein and carbohydrates were also essential in the emulsion with the carrier oil for enhanced stability. Emulsions were prepared using a mixture of casein–carbohydrate conjugate, by Maillard reaction.

The more surface-active of the two composite blocks in milk protein-carbohydrate conjugates—milk protein—adsorbs at the oil/water (o/w) interface in an emulsion system. The hydrophilic component (carbohydrate) permeates most of the emulsion's watery phase. The functions of milk protein and carbohydrates in the operation of conjugate-based emulsifiers are complementary and cooperative [9]. Milk proteins can be more effectively concentrated and mobile in an aqueous solution by being conjugated with carbohydrates, which also increases their solubility and ability to produce emulsions [10]. When milk protein conjugates with a carbohydrate molecule, the carbohydrate molecule acts as a tail and is dragged by the milk protein. Some investigations indicate that the conjugated milk protein molecules migrate across the bulk aqueous phase and toward the o/w interface, despite the fact that the carbohydrate does not normally function as a driving factor for this migration. Strong steric stabilization is another factor contributing to the enhanced emulsion forming abilities of milk protein-carbohydrate conjugates. When oil globules are homogenized, the emulsifier adheres to their surface, limiting their coalescence by steric repulsion [9]. The milk protein's carbohydrate moiety on each oil globule's surface protrudes into the emulsion's aqueous phase during homogenization, preventing high-impact collisions from coalescing [11].

The RSV's solubility in oily matrices was around 0.047 – 0.180 mg ml^{-1} in vegetable oils [12, 13], which was greater than in water at around 0.03 mg ml^{-1}. As a result, oil-in-water type emulsions were employed for RSV encapsulation [4]. Different forms of stabilizers and surfactants have been employed in formulations, including proteins [14, 15], lecithin [8, 16, 17], starches and gums [14, 18], a mixture of these components [19-21]. Protein-carbohydrate conjugates have been offered as a feasible alternative to proteins for use as stabilizing/emulsifying agents due to their superior functional properties. Maillard reaction products have been demonstrated to increase emulsifying properties such as emulsifying, foaming, stabilizing, and solubility [15, 22-24]. Furthermore, as compared to non-reacted proteins, Maillard conjugates have stronger antioxidant activity, which may provide further protection to the bioactive chemicals that have been encapsulated [25]. Accordingly, the purpose of this research is to formulate and evaluate encapsulated spray-dried RSV emulsion.

Materials and Methods

The maltodextrin (20 DE), sodium caseinate was acquired from HiMedia Laboratories and Clarion, India respectively. The soybean oil (Gemini, Cargill India Pvt. Ltd., Gujrat, India) and resveratrol (Kuber Impex Ltd, Indore, India) were purchased from the local market of Indore, India. Other reagents of analytical quality were obtained from (Sigma Aldrich Co, USA) and (HiMedia, Maharashtra, India). Triple distilled water was used to make all aqueous solutions.

Preparation of SC-MD conjugate

The SC-MD conjugate combination (1:1 w/w) was spray-dried after being made in triple-distilled water with 30% total solids and a shear rate of 0.966 PaSec to make the conjugate by the dry technique. The spray-dried combination was then exposed to a desiccator holding a saturated KCl solution for 12 and 24 hr at 60 °C and 80% relative humidity. Afterwards, the samples were left in an ice bath for 20 to 30 min to restrict the maillard reaction, as described by Clark and Tannenbaum [26]. SC-MD conjugate was kept at 6 °C refrigerated conditions for further analysis. The control has only SC and is made in the same way.

RSV microemulsion preparation

The RSV microemulsion was prepared by taking 3.73 mg Resveratrol microemulsion preparation level, 10% oil, 3% SC-MD conjugate for a 5-litre batch then mixing with magnetic stirring for 1 hr at room temperature after this sonication was done for 40 min and pause of 9 sec at 5 °C with the pulse of 60 in an ice bucket. After that, the emulsion was spray-dried (Table 1).

Table 1: Condition for spray drying of emulsion.

Condition	Temperature (°C)
Feed	40
Inlet air	180
Outlet air	90

Particle size

The conjugated and non-conjugated microencapsulated RSV powder dissolved in water (1% solution, w/v) then check the particle size using Mastersizer (Malvern Instruments Ltd. Mastersizer-v3.70).

Scanning electron microscopy (SEM) of microencapsulated RSV powder

For scanning, the microencapsulated RSV powder was gold-coated with a magnetron sputter coater. Using a 20 kV electric current and an FEI Quanta 250 FEG (FEI, Hillsboro, USA), a SEM was used to look at the powder sample's microstructure properties according to the method of Mehra et al. [27].

Rheology of reconstituted microencapsulated RSV powder

Rheology of reconstituted microencapsulated RSV powder was done by using a Rheometer by taking different solutions in water from 1 to 10% of SC-MD, Conjugate, and SC microencapsulated RSV spray-dried.

RSV content by high performance liquid chromatography (HPLC)

RSV content was determined using HPLC according to the methods given by Bolko et al. with some adjustments [28].

Reagent

Solvent A: Mixture of methanol and water 10:90 (v/v)

supplemented with 0.5% (v/v) acetic acid. Methanol used as a mobile phase. The solvent A filtered through 0.45 µm pore size PVDF filters and sonicate for 20 min before injecting them into the HPLC system.

Solvent B: Mixture of methanol and water 90:10 (v/v) supplemented with 0.5% (v/v) acetic acid. The solvent B was filtered through 0.45 µm pore size PVDF filters and sonicate for 20 min before injecting them into the HPLC system.

Procedure

On a reverse-phase HPLC system, analyses were performed (Dionex, Ultimate 3000, USA) using a reverse-phase column C18 having a diameter of 250 mm x 4.6 mm with the size of 5 µm. The flow rate was 1 ml/min, and the column temperature was at 30 °C. The solvent mode was an isocratic elution program with 15 min run time and quantification of all samples was done at 306 nm with a sample injection volume of 20 µl. Based on peak area the RSV content of unknown was calculated using the equation of the standard curve separately.

Results and Discussion

Properties of spray-dried microencapsulated RSV emulsion

As it relates to the emulsion stability, viscosity, and effectiveness in encapsulating bioactive chemicals when emulsions are utilized for compounds, droplet size is a crucial emulsion feature [29, 30]. Spray-dried microencapsulated RSV emulsion containing conjugate's composition was examined using variables such moisture, total solids, protein, fat, ash, and carbohydrates. A variety of factors, including as the drying air input temperature, the feed liquid's viscosity, the concentration of solids, and the droplet residence time in the drying chamber, affect how much water is present in the microencapsulated RSV spray-dried powder.

As shown in Table 1 spray-dried microencapsulated RSV emulsion with conjugate gives 14.2% moisture. Consoli et al. was study the RSV loaded emulsion with conjugate spray-dried powder giving 3.6% total water content [31]. It was discovered that earlier studies using SC-MD as the primary carrier material were similar [32].

Table 2: Compositional analysis of microencapsulated RSV spray-dried powder with conjugate.

Parameters	Percentage
Moisture (%)	14.2 ± 0.14
Total solids (%)	85.78 ± 0.36
Protein (%)	38.20 ± 0.28
Fat (%)	7.81 ± 0.85
Ash (%)	0.83 ± 0.11
Carbohydrate (%)	38.2 ± 0.18

All the triplicates' values are presented as mean values ± SD.

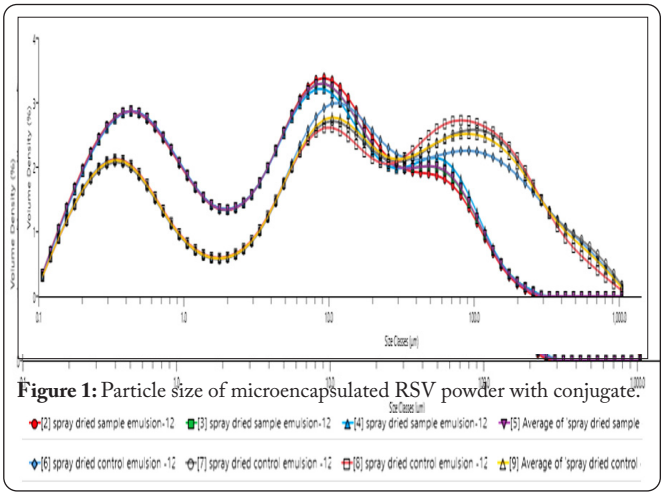

Figure 1: Particle size of microencapsulated RSV powder with conjugate.

Conjugate and SC microencapsulated RSV spray-dried powder had 76.41% and 54.61% encapsulation efficiency, respectively. The conjugated microencapsulated RSV was stable at spray-dried temperature and no degradation of the RSV due to the good carrier of SC-MD as conjugate. Consoli et al. studied the RSV loaded emulsion with conjugate spray-dried powder giving 97.71% encapsulation efficiency [31]. Koga et al. found that the microencapsulation efficiency is up to 68% of RSV microcapsules with SC after spray drying [33].

Regarding microparticle size parameters as shown in Table 3, and Figure 3.1 mean diameter was around [D50] 54.6 µm and [D4,3] 84.4 µm with a span of 1.901. Since the primary components of SC for α, β and k casein, have high molecular masses up to 20 - 25 kDa and slowly adsorb across the surface of the droplets, the size of the emulsion most likely developed as a result, could not cover the entire oil/water interface [34]. The fact that droplets' diameters are constrained by the interpore distance when the majority of the pores are active as adjacent droplets prevent one another from becoming bigger than it, is another factor that contributed to the larger particle size [35].

With Maillard-reacted continuous phase, more polydisperse emulsions with bigger droplets were generated. The polydispersity that is produced by spray-dried powder also causes particle agglomeration because the smaller particles are primarily adhered to the surface of the larger ones. Due to the low molecular mass sugar's plastic behavior, particles' surfaces may become sticky after drying, facilitating their adherence and subsequent agglomeration [36]. Consoli et al. in their study reported the RSV loaded emulsion with conjugate

Table 3: Physico-chemical characterization of microencapsulated RSV spray-dried powder.

Sample	D[4,3] (µm)	D[3,2] (µm)	Dv[10] (µm)	Dv[50] (µm)	Dv[90] (µm)	Span (Dimensionless)	Encapsulation efficiency (%)	RSV loading (mg RSV/gm powder)	Reference
Microencapsulated RSV spray dried powder	84.4	39.3	22.3	54.6	126	1.901	76.41	2.9	
RSV emulsion with SC-MD conjugate by Spray-dried particles	14.31	-	2.98	10.16	25.35	2.20	97.71	0.79	[31]

spray-dried powder had a mean diameter around [D50] 10 μm and [D4,3] 14 μm with a span of 2.20 [31].

SEM of spray-dried microencapsulated RSV emulsion

Spray-dried microencapsulated RSV emulsion with conjugate gives 7 mm of an average diameter like SC and unconjugated which gives 6.5 mm of the average diameter as illustrated in Figure 2 and Figure 3. Results indicated irregular surfaces with different sizes of molecule, sharp, distinctive ,and clear individual spherical particles due to spray drying of microencapsulated RSV emulsion with conjugate and SC. Because of its improved encapsulation effectiveness, conjugate emulsion has a smooth surface devoid of pores and fractures. Spherical structure gives maximum stability owing to the minimum surface area to volume ratio of conjugate and SC emulsion. In conjugate emulsion even with the droplet disruption caused by atomization nozzle in the spray draying process, RSV was able to keep sited within the encapsulating matrix i.e., SC conjugate and not over the particles surface.

A similar report represented that encapsulated RSV emulsion with SC-MD conjugate spray-dried powder particles gives a smooth surface with a spherical shape and smaller particles attached to the bigger one which produces particle agglomeration [31]. The production of bigger particles in the microstructure is caused by MD's hydrophobic interactions with SC molecules [37]. MD and SC molecules interact hydrophobically, which causes the production of bigger particles in microstructure [37]. The size of clusters or particles appeared to be affected by the DE number of MD used.

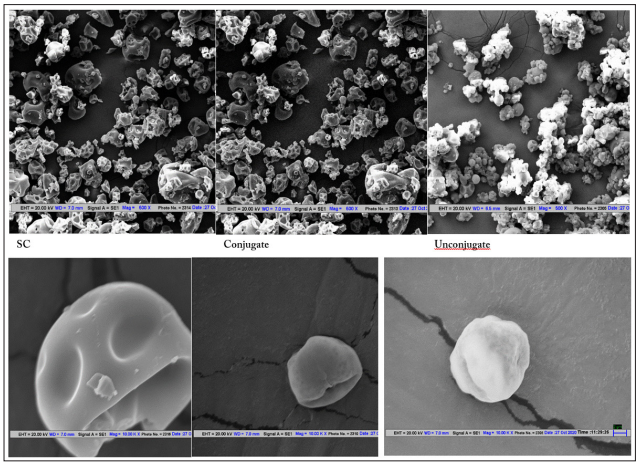

Figure 2: SEM micrograph of microencapsulated RSV emulsion powder at 500X and 10.00KX.

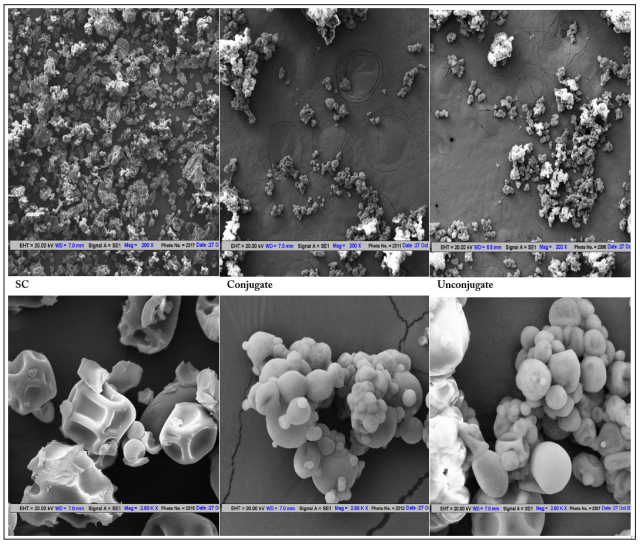

Figure 3: SEM micrograph of microencapsulated RSV emulsion powder at 200X and 2.50KX.

Rheology of reconstituted microencapsulated RSV emulsion

The rheology of reconstituted microencapsulated RSV emulsion with conjugate, unconjugated and SC at different concentrations such as 1 to 10% as shown in Figures 4a - 4f was measured by rheometer in terms of viscosity (Pa.s) and shear stress (Pa) at a different shear rate such as 1, 150, and 300/s. The results showed no statistically significant difference ($p \geq 0.05$) between conjugate, SC, and unconjugated emulsion at varying concentrations of the assessed sample. However, a significant difference ($p \leq 0.05$) was observed to be an increase in concentration on viscosity and shear rate. Viscosity of conjugate emulsion was observed higher at 10% concentration (0.117 ± 0.12 Pa.s) than SC emulsion (0.047 ± 0.15 Pa.s) and unconjugated emulsion (0.008 ± 0.05 Pa.s) at 1/s shear rate. The emulsion viscosity was mainly dependent on the oil phase i.e., lipophilic, aqueous phases, size of oil droplets as well as spray drying influence their behavior by the diffusion of active molecules. Turchiuli et al. discovered that spray drying of oil in water type emulsion increases the viscosity of the spray-dried emulsion powder as the concentration of acacia gum and maltodextrin increases [38].

Conclusion

Regarding microencapsulation of RSV using SC-MD conjugate. Based on the work we've done, composition, increased mean droplet size by 84.4 μm, span 1.90 with encapsulation efficiency around 76.41% and the water content nearby 14.2%. These particle properties resemble spray-dried emulsion particles produced from conventional emulsification techniques in earlier papers, whose droplet sizes can be as small as 1 m. Making solid microparticles for use in food, medicine, and cosmetics can be done very well using spray drying. In the future, we'll look into spray-dried microencapsulated RSV enriched yoghurt, as well as storage studies to see what the advantages and downsides of each emulsification procedure are. The effects of particles that mimicked gastrointestinal disorders should also be considered.

Practical Application

The RSV's assimilation into food products is complicated by its light instability, sensitivity to heat, and ease of oxidation. Bitterness and limited bioaccessibility in the human digestive system are other issues. Encapsulation is a promising processing approach that may aid to enhance oral bioavailability by increasing gastrointestinal fluid solubility, boosting absorption, and preserving RSV from destruction during digestion under pancreatic circumstances. Improve the solubility, gelation, emulsion, and foaming properties of milk protein. Since the conjugate has a hydrophobic core of milk protein and a hydrophilic carbohydrate covering, it may self-assemble into micelles. The conjugate of RSV is used because it acts as a protective vehicle.

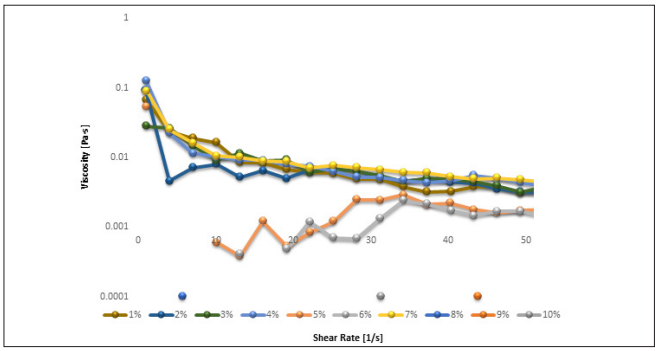

Figure 4a : Effect of concentration on unconjugated spray-dried on viscosity.

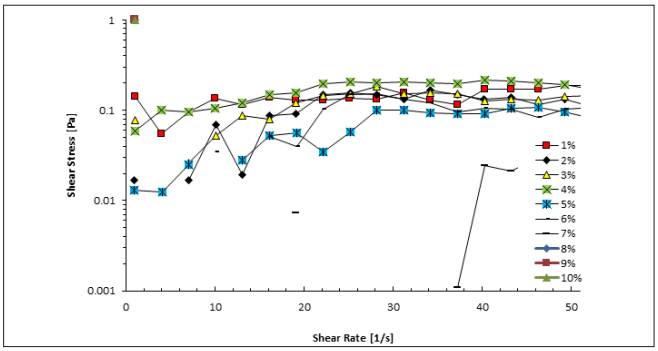

Figure 4b : Effect of concentration on unconjugated spray-dried on shear stress.

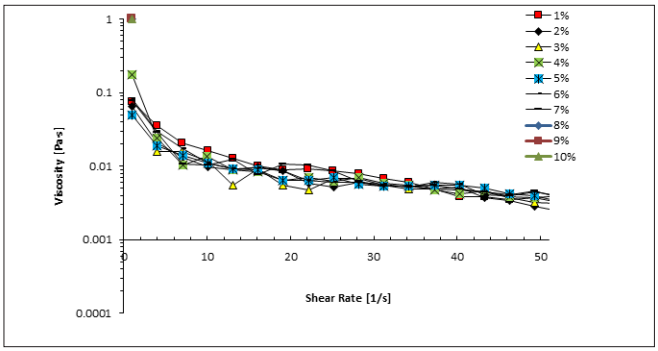

Figure 4c : Effect of concentration on conjugate spray-dried on viscosity.

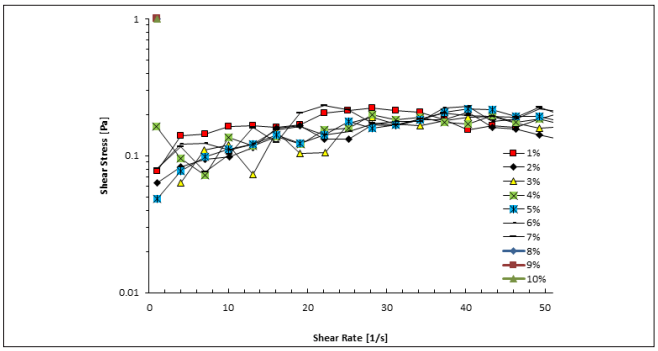

Figure 4d : Effect of concentration on conjugate spray dried on shear **stress.**

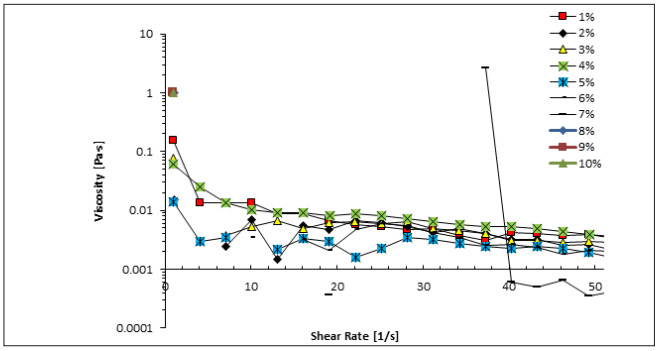

Figure 4e : Effect of concentration on SC on viscosity.

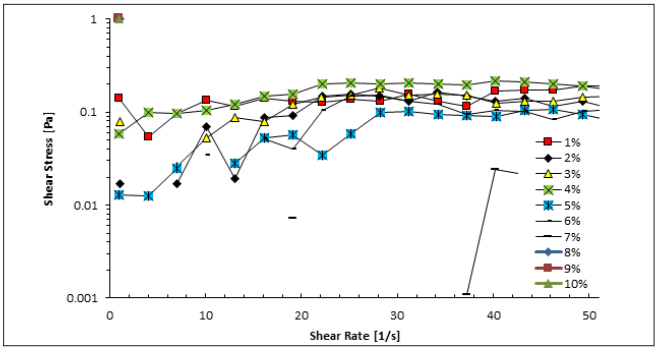

Figure 4f : Effect of concentration on SC on shear stress.

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Conflict of Interest

The authors have declared no conflict of interest.

References

1. Davidov-Pardo G, McClements DJ. 2014. Resveratrol encapsulation: designing delivery systems to overcome solubility, stability and bioavailability issues. *Trends Food Sci Technol* 38(2): 88-103. https://doi.org/10.1016/j.tifs.2014.05.003
2. Kumar H, Choudhary N, Varsha KN, Suman SR. 2014. Phenolic compounds and their health benefits: a review. *J Food Res Technol* 2: 46-59.
3. Devbrat Y, Harish K, Arvind K, Alok J, Pramod K, et al. 2016. Optimization of polyphenolic fortification of grape peel extract in stirred yogurt by response surface methodology. *Indian J Dairy Sci* 69(1): 41-49.
4. Amri A, Chaumeil JC, Sfar S, Charrueau C. 2012. Administration of resveratrol: What formulation solutions to bioavailability limitations? *J Control Release* 158(2): 182-193. https://doi.org/10.1016/j.jconrel.2011.09.083
5. Kumar S, Baniwal P, Kaur J, Kumar H. 2020. Kachnar (*Bauhinia variegata*). In Nayik GA, Gull A (eds) Antioxidants in fruits: properties and health benefits. Springer, Singapore, pp 365-377. https://doi.org/10.1007/978-981-15-7285-2_18
6. Estevinho BN, Rocha F, Santos L, Alves A. 2013. Microencapsulation with chitosan by spray drying for industry applications – a review. *Trends Food Sci Technol* 31(2): 138-155. https://doi.org/10.1016/j.tifs.2013.04.001
7. Rafiq S, Ahmad Nayik G, Kaul R, Kumar H, Ruiz Rodríguez A. 2023. Utilization of maltodextrin and whey protein concentrate for microencapsulation of kinnow peel extract in breadsticks. *Curr Nutr Food Sci* 19(2): 188-196. https://doi.org/10.2174/1573401318666220517200926
8. Donsì F, Sessa M, Mediouni H, Mgaidi A, Ferrari G. 2011. Encapsulation of bioactive compounds in nanoemulsion-based delivery systems. *Procedia Food Sci* 1: 1666-1671. https://doi.org/10.1016/j.profoo.2011.09.246
9. Liu F, Ma C, McClements DJ, Gao Y. 2016. Development of polyphenol-protein-polysaccharide ternary complexes as emulsifiers for nutraceutical emulsions: impact on formation, stability, and bioaccessibility of β-carotene emulsions. *Food Hydrocoll* 61: 578-588. https://doi.org/10.1016/j.foodhyd.2016.05.031

10. Mehra R, Kumar H, Kumar N, Ranvir S, Jana A, et al. 2021. Whey proteins processing and emergent derivatives: an insight perspective from constituents, bioactivities, functionalities to therapeutic applications. *J Funct Foods* 87: 104760. https://doi.org/10.1016/j.jff.2021.104760

11. Corzo-Martínez M, Soria AC, Villamiel M, Olano A, Harte FM, et al. 2011. Effect of glycation on sodium caseinate-stabilized emulsions obtained by ultrasound. *J Dairy Sci* 94(1): 51-58. https://doi.org/10.3168/jds.2010-3551

12. Hung CF, Chen JK, Liao MH, Lo HM, Fang JY. 2006. Development and evaluation of emulsion-liposome blends for resveratrol delivery. *J Nanosci Nanotechnol* 6(9-10): 2950-2958. https://doi.org/10.1166/jnn.2006.420

13. Rafiq S, Sofi SA, Kumar H, Kaul RK, Mehra R, et al. 2022. Physicochemical, antioxidant, and polyphenolic attributes of microencapsulated freeze-dried kinnow peel extract powder using maltodextrin as wall material. *J Food Process Preserv* 46(1): e16177. https://doi.org/10.1111/jfpp.16177

14. Matos M, Gutiérrez G, Coca J, Pazos C. 2014. Preparation of water-in-oil-in-water ($W_1/O/W_2$) double emulsions containing *trans*-resveratrol. *Colloids Surf A Physicochem Eng Asp* 442: 69-79. https://doi.org/10.1016/j.colsurfa.2013.05.065

15. Zhang F, Khan MA, Cheng H, Liang L. 2019. Co-encapsulation of α-tocopherol and resveratrol within zein nanoparticles: impact on antioxidant activity and stability. *J Food Eng* 247: 9-18. https://doi.org/10.1016/j.jfoodeng.2018.11.021

16. Salgado M, Rodríguez-Rojo S, Alves-Santos FM, Cocero MJ. 2015. Encapsulation of resveratrol on lecithin and β-glucans to enhance its action against *Botrytis cinerea*. *J Food Eng* 165: 13-21. https://doi.org/10.1016/j.jfoodeng.2015.05.002

17. Sessa M, Balestrieri ML, Ferrari G, Servillo L, Castaldo D, et al. 2014. Bioavailability of encapsulated resveratrol into nanoemulsion-based delivery systems. *Food Chem* 147: 42-50. https://doi.org/10.1016/j.foodchem.2013.09.088

18. Jain A, Kumar H, Tripathi C, Kulshreshtha S. 2022. A comparative study of *Kigelia pinnata* fruit extracts in terms of antimutagenic potential and antimicrobial efficacy against antibiotic-resistant microbial strains. *Indian J Tradit Knowl* 21(1): 224-233. https://doi.org/10.56042/ijtk.v21i1.28876

19. Chen S, Han Y, Jian L, Liao W, Zhang Y, et al. 2020. Fabrication, characterization, physicochemical stability of zein-chitosan nanocomplex for co-encapsulating curcumin and resveratrol. *Carbohydr Polym* 236: 116090. https://doi.org/10.1016/j.carbpol.2020.116090

20. Diaz-Ruiz R, Martinez-Rey L, Laca A, Álvarez JR, Gutiérrez G, et al. 2020. Enhancing *trans*-resveratrol loading capacity by forcing $W_1/O/W_2$ emulsions up to its colloidal stability limit. *Colloids Surf B Biointerfaces* 193: 111130. https://doi.org/10.1016/j.colsurfb.2020.111130

21. Matos M, Gutiérrez G, Iglesias O, Coca J, Pazos C. 2015. Enhancing encapsulation efficiency of food-grade double emulsions containing resveratrol or vitamin B_{12} by membrane emulsification. *J Food Eng* 166: 212-220. https://doi.org/10.1016/j.jfoodeng.2015.06.002

22. Kumar H, Choudhary N, Garg V, Swami NK, Seth R. 2018. Maillard browning: pros and cons in dairy and food industries. *J Dairy Sci Technol* 2(2): 9-18.

23. Li R, Cui Q, Wang G, Liu J, Chen S, et al. 2019. Relationship between surface functional properties and flexibility of soy protein isolate-glucose conjugates. *Food Hydrocoll* 95: 349-357. https://doi.org/10.1016/j.foodhyd.2019.04.030

24. Nooshkam M, Varidi M, Verma DK. 2020. Functional and biological properties of Maillard conjugates and their potential application in medical and food: a review. *Food Res Int* 131: 109003. https://doi.org/10.1016/j.foodres.2020.109003

25. Kchaou H, Benbettaieb N, Jridi M, Nasri M, Debeaufort F. 2019. Influence of Maillard reaction and temperature on functional, structure and bioactive properties of fish gelatin films. *Food Hydrocoll* 97: 105196. https://doi.org/10.1016/j.foodhyd.2019.105196

26. Clark AV, Tannenbaum SR. 1970. Isolation and characterization of pigments from protein-carbonyl browning systems. Isolation, purification, and properties. *J Agric Food Chem* 18(5): 891-894. https://doi.org/10.1021/jf60171a040

27. Mehra R, Kumar S, Singh R, Kumar N, Rathore D, et al. 2022. Biochemical, dielectric and surface characteristics of freeze-dried bovine colostrum whey powder. *Food Chem X* 15: 100364. https://doi.org/10.1016/j.fochx.2022.100364

28. Bolko K, Zvonar A, Gašperlin M. 2014. Mixed lipid phase SMEDDS as an innovative approach to enhance resveratrol solubility. *Drug Dev Ind Pharm* 40(1): 102-109. https://doi.org/10.3109/03639045.2012.749888

29. Jafari SM, Assadpoor E, He Y, Bhandari B. 2008. Encapsulation efficiency of food flavours and oils during spray drying. *Dry Technol* 26(7): 816-835. https://doi.org/10.1080/07373930802135972

30. McClements DJ. 2004. Food Emulsions: Principles, Practices, and Techniques. Boca Raton, CRC press. https://doi.org/10.1201/9781420039436

31. Consoli L, Hubinger MD, Dragosavac MM. 2020. Encapsulation of resveratrol using Maillard conjugates and membrane emulsification. *Food Res Int* 137: 109359. https://doi.org/10.1016/j.foodres.2020.109359

32. Hogan SA, McNamee BF, O'Riordan ED, O'Sullivan M. 2001. Microencapsulating properties of sodium caseinate. *J Agric Food Chem* 49(4): 1934-1938. https://doi.org/10.1021/jf000276q

33. Koga CC, Andrade JE, Ferruzzi MG, Lee Y. 2016. Stability of *trans*-resveratrol encapsulated in a protein matrix produced using spray drying to UV light stress and simulated gastro-intestinal digestion. *J Food Sci* 81(2): C292-C300. https://doi.org/10.1111/1750-3841.13176

34. Morris GA, Sims IM, Robertson AJ, Furneaux RH. 2004. Investigation into the physical and chemical properties of sodium caseinate-maltodextrin glyco-conjugates. *Food Hydrocoll* 18(6): 1007-1014. https://doi.org/10.1016/j.foodhyd.2004.04.013

35. Dragosavac MM, Sovilj MN, Kosvintsev SR, Holdich RG, Vladisavljević GT. 2008. Controlled production of oil-in-water emulsions containing unrefined pumpkin seed oil using stirred cell membrane emulsification. *J Membr Sci* 322(1): 178-188. https://doi.org/10.1016/j.memsci.2008.05.026

36. Bhandari BR, Datta N, Howes T. 1997. Problems associated with spray drying of sugar-rich foods. *Dry Technol* 15(2): 671-684. https://doi.org/10.1080/07373939708917253

37. van der Linden E, Foegeding EA. 2009. Gelation: Principles, Models and Applications to Proteins. In: Kasapis S, Norton IT, Ubbink JB (eds) Modern Biopolymer Science. Academic Press, pp 29-91. https://doi.org/10.1016/B978-0-12-374195-0.00002-1

38. Turchiuli C, Munguia MJ, Sanchez MH, Ferre HC, Dumoulin E. 2014. Use of different supports for oil encapsulation in powder by spray drying. *Powder Technol* 255: 103-108. https://doi.org/10.1016/j.powtec.2013.08.026