Table 2: Stress sweep test and linear viscoelasticity range for gelling agents.

Gelling agent		G' (Pa)*	G" (Pa)*	Tan δ*	G' = G'' (Pa)	Crossing point of G' and G" (Pa)
Carbopol 940	1%	429.24±42.12^{efg}	52.16±9.77^{hi}	0.097±0.016^{f}	97.6	256.3
	3%	503.29±35.89^{ef}	42.14±10.52^{i}	0.079±0.019^{f}	115.3	306.1
	5%	752.25±33.82^{fg}	68.99±7.57^{hi}	0.086±0.004^{f}	184.5	499.3
Fish gelatin 250 bloom	1%	2.66±0.20^{g}	2.93±0.35^{i}	2.932±0.350^{ef}	-	-
	3%	15.52 ± 4.77^{fg}	3.84 ± 2.71^{i}	0.361 ± 0.217^{f}	6.6	6.846
	5%	360.43±16.31^{efg}	69.51±10.67^{hi}	0.188±0.039^{f}	115.8	87.36
Guar gum	1%	17.22±0.72^{g}	16.69±0.33^{i}	0.964±0.021^{f}	16.4	4.63
	3%	282.65 ± 20.75^{efg}	138.45 ± 7.25^{gh}	0.501 ± 0.085^{f}	156.1	351.1
	5%	2598.52±67.49^{cd}	777.95±27.39^{d}	0.299±0.01^{f}	1239.3	966.1
ι-carrageenan	1%	2.03±0.64^{g}	2.76±0.28^{i}	1.082±0.059^{f}	-	-
	3%	245.15 ± 33.75^{fg}	43.49 ± 16.19^{i}	0.203 ± 0.079^{f}	82.5	269.7
	5%	689.67±15.46^{e}	67.63±5.65^{hi}	0.095±0.005^{f}	218.8	504.2
κ-carrageenan	1%	6.06±0.83^{g}	2.27±0.20^{i}	0.420±0.156^{f}	6.4	1.38
	3%	226.20 ± 33.90^{fg}	62.38 ± 15.3^{hi}	0.316 ± 0.088^{f}	51.8	73.30
	5%	680.08±40.10^{e}	182.15±5.31^{g}	0.260±0.033^{f}	161.3	138.4
Kelcogel F	1%	58.90±6.04^{g}	29.50±0.64^{i}	0.718±0.418^{f}	27.03	18.89
	3%	2391.00 ± 91.00^{d}	364.65 ± 14.85^{f}	0.166 ± 0.017^{f}	1923.8	347.8
	5%	8433.48±213.71^{b}	1227.5±28.10^{b}	0.144±0.014^{f}	3455.0	226.70
Konjac gum	1%	710.41±4.74^{e}	290.58±9.53^{f}	0.425±0.026^{f}	298.1	549.5
	3%	2848.50 ± 192.50^{c}	999.4 ± 134.6^{c}	0.341 ± 0.032^{f}	1323.2	1472.2
	5%	12 222±669.50^{a}	2812.22±48.10^{a}	0.221±0.027^{f}	5367.1	2636.1
Methocel E4M	1%	0.84±0.02^{g}	2.08±0.04^{i}	3.55±0.27^{ef}	-	-
	3%	16.44± 0.54^{g}	37.82 ± 19.76^{i}	2.358 ± 0.612^{ef}	-	-
	5%	426.67±3.07^{efg}	572.93 ±4.80^{e}	1.346±0.016^{f}	-	-
Methocel F50	1%	0.01±0.00^{g}	0.08±0.01^{i}	15.278±2.25^{b}	-	-
	3%	0.40 ± 0.40^{g}	1.18 ± 0.44^{i}	689.912 ± 688^{a}	-	-
	5%	1.23±0.04^{g}	8.33±0.12^{i}	6.951±0.362^{cde}	-	-
Methocel SGA 7C	1%	0.012±0.01^{g}	0.59±0.43^{i}	9.370±1.374^{c}	-	-
	3%	1.58 ± 1.25^{g}	3.52 ± 2.17^{i}	3.406 ± 3.406^{ef}	-	-
	5%	1.29±0.30^{g}	3.71±0.22^{i}	4.091±0.603^{def}	-	-
Methyl cellulose HV	1%	0.12±0.01^{g}	0.89±0.02^{i}	8.421±1.262^{cd}	-	-
	3%	45.99 ± 11.66^{g}	39.31 ± 7.88^{i}	0.795 ± 0.121^{f}	41.6	49.23
	5%	294.47±10.16^{efg}	174.26±7.17^{g}	0.603±0.021^{f}	143.4	380.6

*Values are Mean + SD. Statistical analysis were expressed using alphabetical superscript where different alphabet in each group means the data were statistically significant different ($p < 0.05$), while the same alphabetical superscript means they are statistically not significant different ($p > 0.05$)

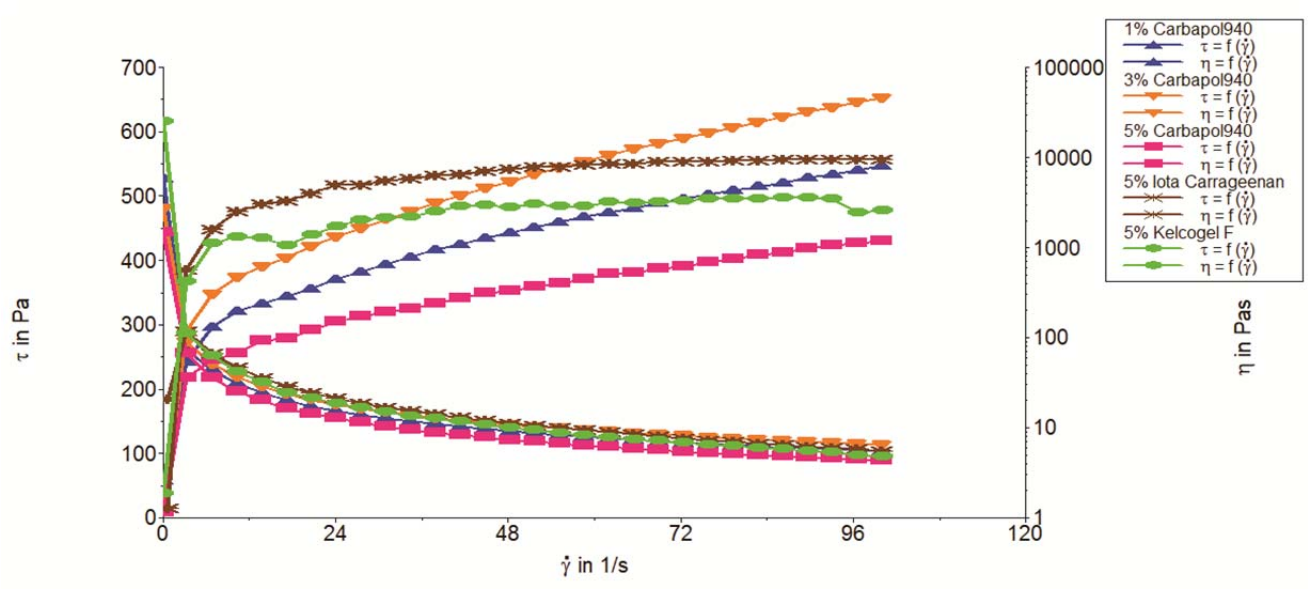

Fig. 1: Shear stress and viscosity *vs*. shear rate of some good gelling agents.

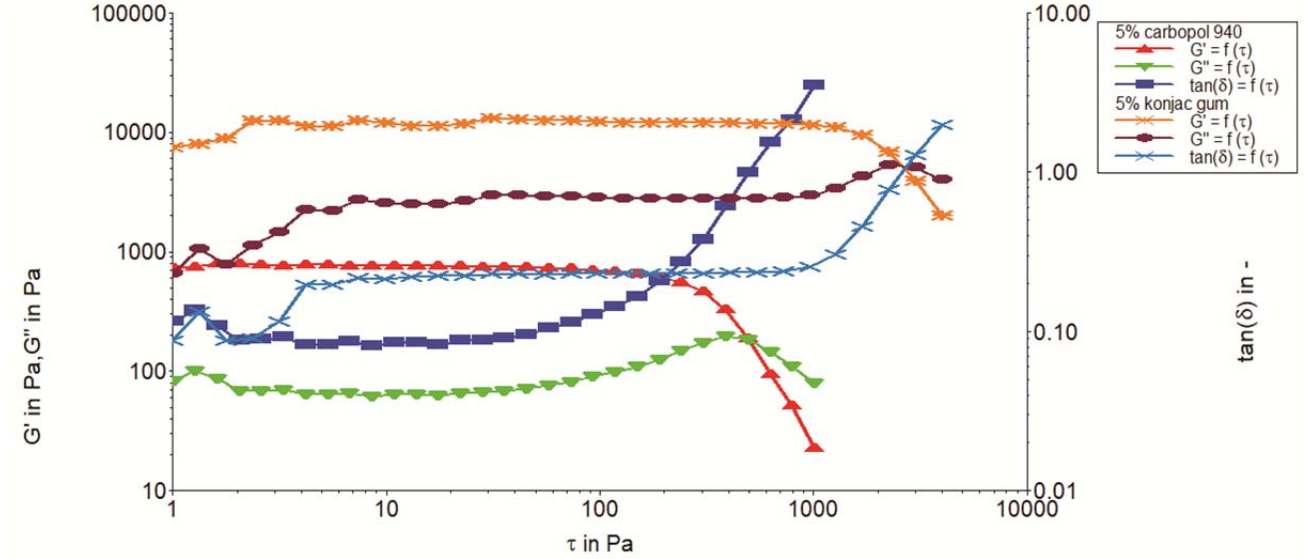

Fig. 2: Stress sweep test of some good candidate gels (carbopol 940® and kelcogel F).

CONCLUSION

The gels rheological profiles including the apparent viscosities at 3 shear rates, rheological modeling, consistency factor (*K*), flow behavior index (*n*), values of G', G", and the crossing points of G' and G" for all 11 gelling agents at 3 different concentrations were demonstrated and discussed for their suitability as dental gels. Various gelling agents exhibited potential rheological profiles for dental applications. These includes 3% and 5% carbopol 940, 5% guar gum, 5% ι-carrageenan, 3% kelcogel F, and 1%, 3% and 5% konjac gum. These gels were found to be viscoelastic, yet consistent in behaving as pseudoplastic gel with acceptable viscosity profiles at high shear rates (100 s^{-1}), having high consistency factor (*K*), good flow behavior (*n*), high value of G', and the crossing points of G' and G" happened at high shear stress. Other gels such as 1% carbopol 940, 3% and 5% of guar gum and ι-carrageenan, 1% and 5% of kelcogel F, 1%, 3% and 5% concentrations of fish gelatin, κ-carrageenan, methocel E4M, methocel F50, and methocel SGA 7C and methyl cellulose HV might not be good candidates due to their low viscosity or their viscous behavior overtook their elasticity behavior. This study suggests variable gelling agents as vehicles for dental gels. Hence, it gives the formulator more options other than the limited available gels used frequently as dental gels.

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DECLARATION OF INTEREST STATEMENT

There is no conflict of interest regarding this research and written content.

REFERENCES

1. Das B, Nayak AK, Nanda U. Topical gels of lidocaine HCl using cashew gum and Carbopol 940: preparation and in vitro skin permeation. Int J Biol Macromol. 2013;62:514-7. doi: 10.1016/j.ijbiomac.2013.09.049. PubMed PMID: 24099938.
2. Abid Hussain GMK, Syed Umer Jan, Shefaat Ullah Shah, Kifayatullah Shah,, Muhammad Akhlaq NR, Asif Nawaz and Abdul Wahab. Effect of olive oil on transdermal penetration of flurbiprofen from topical gel as enhancer. Pak J Pharm Sci. 2012;25(2):365-9.
3. Malathi K, Jeevrekha M, Rajula MPB, et al. Local Drug Delivery –A Targeted Approach. International Journal of Medicine and Biosciences. 2014;3(2):29-34.
4. Raghavendra Rao NG, Rao K, Muthalik S, et al. Clinical studies and antimicrobial activity of ciprofloxacin hydrochloride medicated dental gels for periodontal infection. Asian Journal of Pharmaceutics. 2009;3(2):125-34. doi: 10.4103/0973-8398.55050.
5. Jones DS, Woolfson AD, Brown AF, et al. Design, characterisation and preliminary clinical evaluation of a novel mucoadhesive topical formulation containing tetracycline for the treatment of periodontal disease. Journal Of Controlled Release. 2000;67:357-68.
6. Sharma LA, Love RM, Ali MA, et al. Healing Response of Rat Pulp treated with Injectable Keratin Hydrogel. J Appl Biomater Funct Mater 2017;15(3):244-50.
7. Phaechamud T, Mahadlek J, Chuenbarn T. In situ forming gel comprising bleached shellac loaded with antimicrobial drugs for periodontitis treatment. Materials and Design. 2016;89:294-303.
8. Ersch C, Meinders MBJ, Bouwman WG, et al. Microstructure and rheology of globular protein gels in the presence of gelatin. Food Hydrocolloids. 2015 30 September 2015
9. Rowe RC, Sheskey PJ, Quinn ME. Handbook of Pharmaceutical Excipients. 6 ed.: Pharmaceutical Press; 2009.
10. Agnihotri S, Wakode S, Agnihotri A. Formulation and Evaluation of Herbal Antiacne Gel of Myrica Esculenta. Asian Journal of Pharmaceutical and Clinical Research. 2016;9(4):358-61.
11. Kaleemullah M, K. J, M. GT, et al. The Effect of various vehicles on in-vivo performance of indomethacin from different topical formulations. World Journal of Pharmaceutical Research. 2015;4(4):157-72.
12. Kassab JK, Thomas LM, Jabir SA. Development and Physical CHaracterisation of a Periodontal Bioadhesive Gel of Gatifloxacin. International Journal of Applied Pharmaceutics. 2017;9(3):31-6.
13. Ibrahim NH, Che Man Y, Tan CP, et al. Mixture-Design-Experiment-on-Flow-Behaviour-of-OW-Emulsions-as-Affected-by-Polysaccharide-Interactions. International Journal of Biological, Biomolecular, Agricultural, Food and Biotechnological Engineering. 2010;4(7):464-70.
14. de Cássia da Fonseca V, Haminiuk CWI, Izydoro DR, et al. Stability and rheological behaviour of salad dressing obtained with whey and different combinations of stabilizers. International Journal of Food Science & Technology. 2009;44(4):777-783. doi: 10.1111/j.1365-2621.2008.01897.x.
15. Markis F, Baudez J-C, Parthasarathy R, et al. Rheological characterisation of primary and secondary sludge: impact of solids concentration. Chemical Engineering Journal. 2014. doi: http://dx.doi.org/10.1016/j.cej.2014.05.085.
16. Ricci EJ, Bentley MVLB, Farah M, et al. Rheological characterization of Poloxamer 407 lidocaine hydrochloride gels. Europian Journal of Pharmaceutical Sciences. 2002;17:161-7.
17. Binsi PK, Shamasundar BA, Dileep AO, et al. Rheological and functional properties of gelatin from the skin of Bigeye snapper (Priacanthus hamrur) fish: Influence of gelatin on the gel-forming ability of fish mince. Food Hydrocolloids. 2009;23(1):132-145. doi: 10.1016/j.foodhyd.2007.12.004.
18. Ibrahim NH, Ching CW, Rozaini MZH. Flow properties of o/w emulsions as affected by xanthan gum, guar gum and carboxymethyl cellulose interactions studied by a mixture regression modelling. Food Hydrocolloids. 2016;53:199-208.
19. Lewis MJ. Physical properties of foods and food processing systems. Elsevier; 1990.
20. Di Giuseppe E, Corbi F, Funiciello F, et al. Characterization of Carbopol® hydrogel rheology for experimental tectonics and geodynamics. Tectonophysics. 2015;642:29-45. doi: 10.1016/j.tecto.2014.12.005.
21. Tipvarakarnkoon T, Senge B. Rheological behaviour of gum solutions and their interactions after mixing. Annual transactions of the nordic rheology society. 2008;16.
22. Weiss RG. The Past, Present, and Future of Molecular Gels. What Is the Status of the Field, and Where Is It Going? Journal of The American Chemical Society. 2014;136(21):7519-30. doi: 10.1021/ja503363v.
23. Angelova LV, Terech P, Natali I, et al. Cosolvent gel-like materials from partially hydrolyzed poly (vinyl acetate) s and borax. Langmuir. 2011;27(18):11671-82.
24. Nagelreiter C, Raffeiner S, Geyerhofer C, et al. Influence of drug content, type of semi-solid vehicle and rheological properties on the skin penetration of the model drug fludrocortisone acetate. Int J Pharm. 2013;448(1):305-12. doi: 10.1016/j.ijpharm.2013.03.042. PubMed PMID: 23541986.
25. Derkach SR, Ilyin SO, Maklakova AA, et al. The rheology of gelatin hydrogels modified by k-carrageenan. LWT- Food Science and Technology. 2015;63(1):612-9.
26. Qiao L, Li Y, Chi Y, et al. Rheological properties, gelling behavior and texture characteristics of polysaccharide from Enteromorpha prolifera. Carbohydrate Polymers.2016;136:1307-14.