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Application Of Glucono-Delta-Lactone Acid (GDL) Infoods System: A Review

Raqad R. Al-Hatim[1]; Zena Kadhim Al-Younis[1]; Najlaa K. Issa[2]; Sarmad Ghazi Al-Shawi[1]

[1]Department of Food Science, College of Agriculture, University of Basrah, Iraq

[2]Department of Chemistry, College of Science, University of Duhok, Region of Iraq

Abstract

Glucono delta-lactone (GDL) is considered a processed product or ingredient being non-synthetic utilized in processing as organic for all applications safely. Mostly, food GDL uses relies on its chelating and acidic characteristics. GDL effects were inspected on cooked rice and the system of noodles. GDLis of many substances physical and chemical characteristics such as melting and boiling points, malleability, conductivity and capacity of heat besides functional characteristics where these characteristics collectively distinguished it and render it's as applications for food being safe. Glucose naturally exists in several foods. Once it reacts with atmospheric O_2, some oxidize to GA with the aid of glucose oxidase. Once GA takes place in H_2O presence, some of it might cyclize to GDL along with the involvement of the gluconate shunt where GDL is made from the GA aqueous solution through direct crystallization of GA for food utilization that might be produced in one of the 3 diverse methods (chemical, enzymatic and microbial). GDL food applications were performed in different products such as; dairy as a coagulant and gelling agent, bakery, cereal seed, meat, seafood, tofu, sauces and dressings. Moreover, GDL is ofantioxidant activity, since it is occurring naturally as polyhydroxy acid (PHA) along with the metal chelating, antioxidant and moisturizing activity. Also,GDL considered an antimicrobial, extending shelf-life and minimizing total counts of microbes in products due to pH lowering which prevents bacterial growth and hastens the drying.**Aims**The aim of this review is to (1) add the GDL into food products such dairy products, meat products, beverages and ect due to its ability to reduce the pH value and create a gelatinous network; (2) study the capability of GDL to work as antioxidants and antimicrobial agents.

Keywords: Glucono-delta-lactone (GDL), Acid-induced-gelation

Introduction

Currently, glucono delta-lactone(GDL) is permitted under the program regulations of national organic at 7CFR 205.605(a). It is permitted as processed products or ingredient being non-synthetic that is labeled as "organic".Generally, it might be utilized in processing as organic for all applications safely. GDL might be added to foods as a pickling agent or curing, anagent of leavening, an agent tocontrol pH, and as a sequestrant (21CFR 184.1318). It was petitioned originallyfor utilizing as acoagulant for tofu.Mostly,food GDL usesrelies on its chelating and acidic characteristics. Initially,the taste is sweetwhen H_2O is added to

GDL. Then,to gluconic acid (GA),it hydrolyzes which offering a marginally sweet, somewhat acidic taste. In various foods, it is favored to other acids whichproviderobust, extratastes being acidic.If GDL is dissolved in H_2O, it will yieldGA. Its slow attribute dissolution renders its taste fewer tart compared to other organic acids(Jungbunzlauer, 2008; Rubico and McDaniel, 1992).

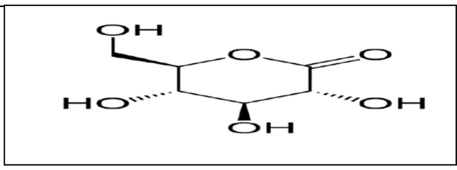
GDL has been utilized as an agent of coagulating in tofu processing as well as for the formation of curd cheese and milk heat stability in industries of dairy.GDL effects were inspected on cooked rice andnoticed that the textural and microbial cooked rice qualities thatwere prepared with GDL and CH_3COOH at a concentration above 0.1 % exposed a noteworthy improvement. The cooked rice hardness thatwas prepared with both acidulants enlarged, signifyingretrogradationtook placequicker with acids presence. The study outcome may be beneficial in predicting rice-based noodles'textural qualities. Alternatively, the GDL utilized in the system of noodles was reported in Japanese udon. Such is a product of wheat and in the supermarket is currently marketed as a product as shelf-stable. GDL is added into a mix of udon flour for providing a low system of pH for prolongingsuch wheat-based noodles shelf life (Sumitraet al., 2006;Low et al., 2020).

Substances physical and chemical characteristics

Severalsubstances physical characteristicsdifferbased on the substance quantitywhereas othersubstances physical characteristics do not differbased on the substance quantity, the volume and mass do not differbased onthe substance quantity but, melting and boiling points, malleability, conductivity and capacity of heat do differ based on the substance quantity.

Table (1): General characteristics of Glucono-Delta- Lactone

Glucono-Delta- Lactone	**Properties**
Chemical formula	$C_6H_{10}O_6$
Color	White, odorless practically, crystalline powder
CAS registry #	[90-80-2]
Trade name(s)	GDL
Chemical name	D-Glucono-1, 5-lactoneGluconolactone; Delta-gluconolactone; 1, 5-Gluconolactone; D-(GA) lactone; GDL; D-(GA).

Food additives E numbers(other codes)	E575
pKa	3.70
pH	3.6
Solubility	Highly soluble, 5.9 x 105 mg/L 25 °C sparingly soluble in alcohol
Density	1.68 g/ml
Vapor pressure	2.41 x 10-9 hPa at 25°C
Melting point	153 °C
Boiling point	398.5°C
Relative molecular mass	178.14 g/mol
Nature	Non-volatile organic acid, nontoxic
Representative structure	

(Kim et al., 2016;U.S.EPA 2019)

Functional characteristics ofGlucono-Delta- Lactone

1- Leavening agent.
2- Bufferin agent.
3- Gelling agents.
4- Emulsification agent.
5- Pickling agent.
6- Chelating agent.
7- Edible coating
8- Color stabilizing.
9- H_2O-biding capacity.
10- Viscosity.

(Anonymous,1981: Liet al., 2011; Liu et al.,2019; Anonymous, 2020)

Antioxidantactivity of GDL

GDL is occurring naturally aspolyhydroxy acid (PHA) along with the metal chelating, antioxidant and moisturizing activity.GDL can be formed viaD-glucose oxidationas enzymatic oxidation. Its capacity in scavenging free radicals explains its antioxidant activity(Anonymous,1981;Zeng et al., 2017;Anonymous, 2020).

Antimicrobial activity of GDL

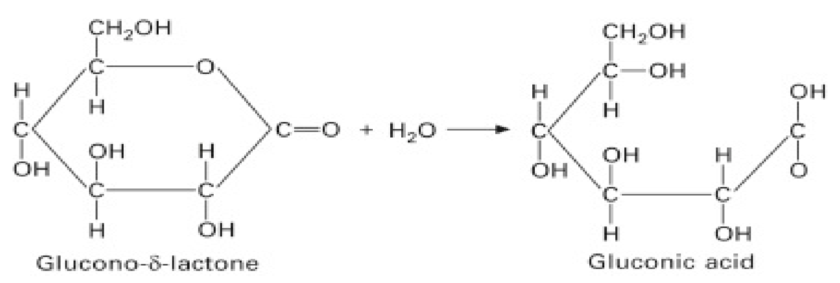
GDLconsidered an antimicrobial, extending bologna shelf-life and minimizing total counts of microbes in products of pork and beef. The pH lowering preventsbacterial growth and hastens the drying (Bertelsenet al., 1995; Søltoft-Jensenand Hansen, 2005).GDL found to be effective in preventing the growth of Listeria monocytogenes when used in combination with lactate in emulsion type meat products. Also, it was found that the lowering of pH by GDL together with lactate significantly improved the oxidative stability of the meat product and resulted in higher (Juncheret al., 2000;Sameliset al.,2002)

Substance source

Glucose naturally exists in several foods. Once it reacts with atmosphericO_2, some oxidize toGA.GA can be presentup to 1% in honey, up to 0.25%in wine,meat,rice, and vinegar. In honey,the amounts are higher due to the glucose oxidase enzyme presence, where salivary secretion occurs; hence, some enzymatic conversionisthere. Wherever GAtakes place in H_2Opresence, some of it might cyclize to GDL(Ramachandran et al., 2006; Wong et al., 2008).

GDLcomposition

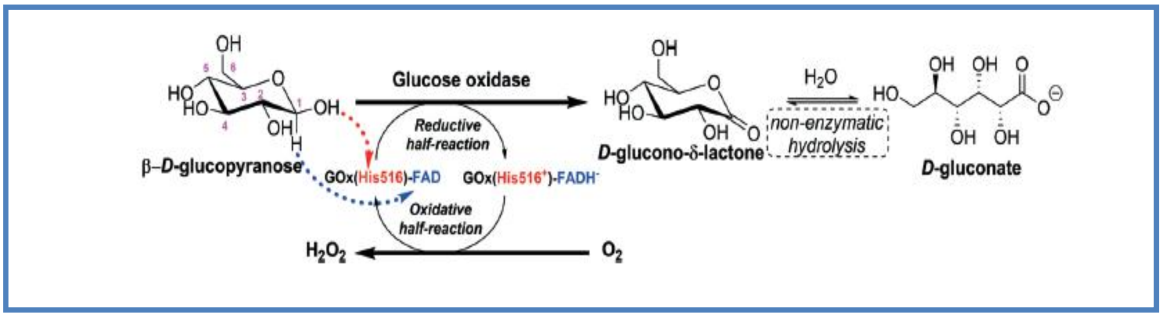
D-glucose is considered as aldohexose, it is a sugar of 6-Ccomprisingthe group asan aldehyde. Ifthe group of aldehyde is oxidized to a carboxylic acid, D-GAisproduced. The C adjacent to the acidgroup (32) is called α (C2), the following one is β (C3), the following isɣ (C4), and the following is theδ(C5). D-GAcan respondalong with itself, producing lactone asa cyclic ester. If the reaction is between C1 of the acid group and delta(C5) of the hydroxyl group, the lactone is termed -D-glucono-delta-lactone, D-glucono-1,5-lactone or D-36 GDL. GDL isconsidered as an inner, neutral GAcyclic ester formed viaglucoseacid fermentation. It takes place naturally in wine, honey, fruit juices and severalproducts being fermented. GDL is a glucose derivate such as a saccharic acid and is a ring-shaped molecule. GDL exhibits 6C atoms, and the group as OH is linked on each C atom(Ramachandran et al., 2006:Feiner, 2016).



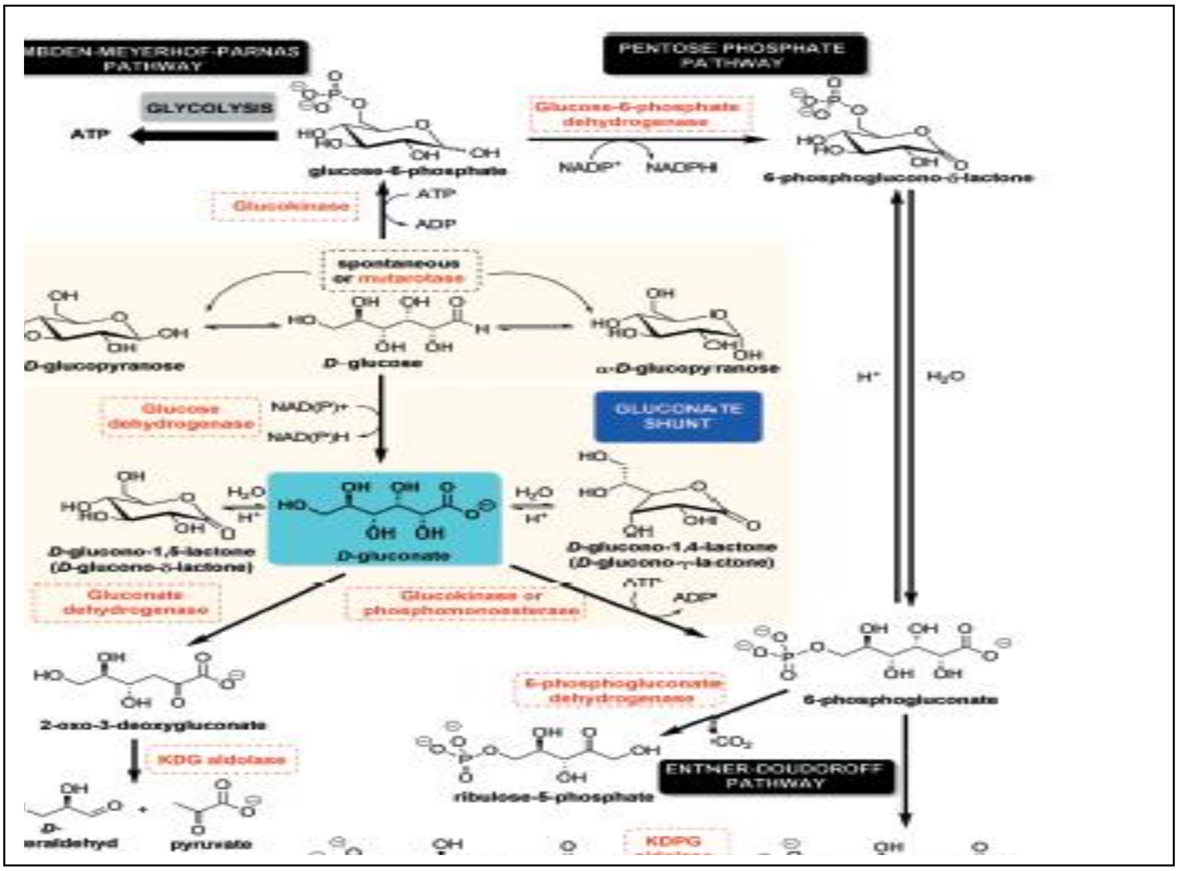
Figure(1):Glucono-delta -lactone (GDL) and(GA). (**Feiner,2016)**

Glucose oxidase: source and action mechanism

GA (penta-hydroxycaproic acid, Figure2) isformed from glucosevia a simple reaction of dehydrogenation catalyzedvia glucose oxidase. Aldehyde group oxidation on C-1 β -D-glucose to a carboxyl group causesglucono-delta-lactone ($C_6H_{10}O_6$) production and H_2O_2(Figure 2). Glucono-d-lactone is extrahydrolyzed to GAeither spontaneously or via lactone hydrolyzing enzyme, whereas$H_2O_2$is decomposed to H_2O and O_2via peroxidaseenzyme(Ramachandran et al.,2006;Korneckiet al., 2020).



Figure(2):Glucose oxidase mechanism in glucose oxidation to D-glucono-delt–lactone



(Leskovacet al.,2005;Bankaret **al.,2009)**

Figure (3): The gluconate shunt(Kornecket al., 2020)

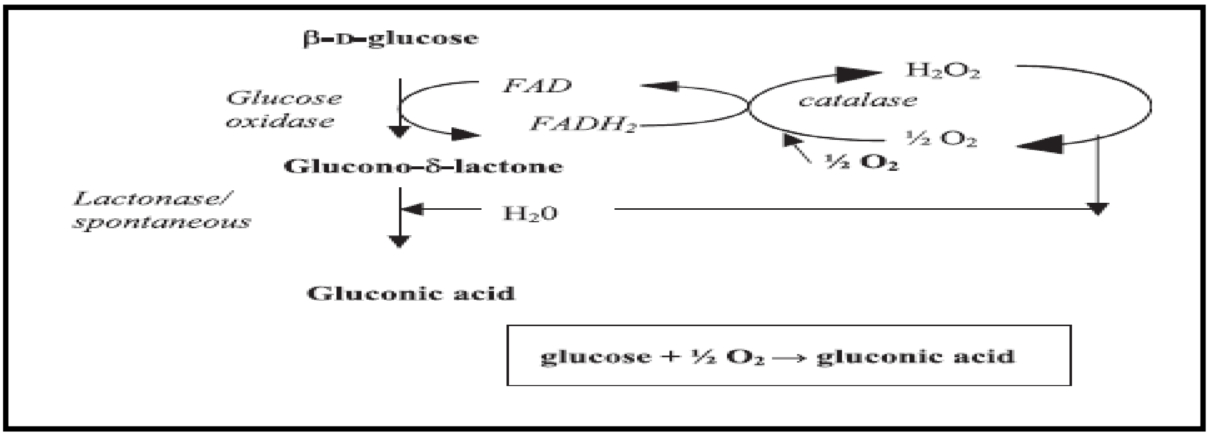
GDL production method

GDL is manufactured commercially from sources being renewable as carbohydrate viafermentation as microbial,then viaprocessing of downstream. Throughoutsucha process, GDL is formed besideGAthroughthe fermentation ofglucose.GDL is madefrom the GAaqueous solution through direct crystallization ofGAfor food utilization in Americathat might be produced in one of the3diversemethods (FDA, 21CFR184.1318).

Table(2): Different acid glucono-delta-Lactonoeproduction methods

Methods	Oxidation	Usedsubstances
Chemical	D-glucose oxidation	Bromine H_2O
Microbial	D-glucose oxidation	Microorganisms that are non--toxicogenic and non-pathogenic
Enzymatic	D-glucose oxidation	Enzymes resulting from such microorganisms

GDL is GA neutral cyclic ester.The acid is produced by aerobic carbohydrate source fermentation i.e.,syrup of glucose derived from maize. Following fermentation,purification and crystallization will be performed. GDL dissolves quickly once itis added to the solution being aqueous. Then, it progressively hydrolyses toGAand the taste changes to slightly acidic from somewhat sweet (Haynes, 2010).GAis produced customarily via fermentation utilizing Aspergillus niger. Glucose catalase and oxidase genes from A. nigerhave been identified through isolation. GAformation might be improved bycloned genes utilization and alternative systems of the economic host may be developed (Nagarajan, 1992; BeMiller, 1992). Glucose oxidase-catalyzed D-glucose oxidation is a utilized method in commercial GDL production (Figure 3)**.**



Figure(4): Fermentationmethod in glucose oxidation by Aspergillus niger(Ramachandran et al.,2006).

GDL application in the food system

Applications of food are occurring naturally in honey, fruit, wine, and kombucha tea that able to be formed viarenewable raw materials fermentation whichisreadily bio-degradable, sustainable, and the products being safe. The food applications for the product group containGA, GDLis a food additive as naturally-occurring is utilized as an acidifier, a sequestrant, or a curing, leavening agent or pickling. It isD-GA cyclic ester(Anonymous, 2020).In the food industry, GAis an organic acid mild thathaving applications. As indicated above, it is constituent beingnatural in honey and fruit juices and is utilizedin foods pickling. Its glucono-d-lactonesinner ester, divulges a sweet taste initially that becomeslater somewhat acidic.

It is utilized in products of dairy and meat, principally in baked goods as a leaveningagent component of products thatpreleavened. It is utilized as an agent of flavoring (i.e., in sherbets) andin decreasing fat absorption in cones and doughnuts. Food-stuffs comprising D-glucono-delta-lactone includeyogurt, bean curd, bread, cottage cheese, meat and confectionery.In general, GAalongwihits,saltsisutilized in food formulation (Table 3). Also,GAis utilized as a mineral(Ramachandran et al.,2006;Liuet al., 2019).

Table(3): Levels of (GDL) addition to foods (Anonymous, 1981)

Food type	Weighted mean%
Baked goods, baking mixes	0.31
Milk products	1.01
Cheese	1.00
Beverages	0.25
Meat products	0.15
Dairy products analogs	0.20

Table (4): Overview ofmajor GDL food applications

Produce	Function	References
Dairy	Acidifier, coagulant, In the industry ofdairy for theformation of cheese curd and for improvement of heat milkstability replacement of starter cultures	Ramachandranet al.(2006)
Bakery	Leavening agent	Jungbunzlauer (2009)
Cereal seed	wheat-based noodles,the quality of the noodles was improved dramatically	Low et al.(2020)
Meat	Curing agent, Phosphate replacement, stabilizer Slow acting acidulant in theprocessing of meat i.e., sausages	Yilmaz &Zorba (2010);Yimet al.(2015)
Seafood	Replacement for sulfites, acidifier, preservation	Senturket al.(2018)
Tofu	Soybean protein coagulation in tofu manufacturing	Chang(2006)
Saucesand dressings	A chelating agent, acidifier, preservation	PMP(2004)
Convenience food	Preservation, lowering pH	Low et al.(2020)
Microencapsulation	The stability of enhanced free cell and encapsulated of probiotic bacteria Lactobacillus casei and the increase in the efficiency of encapsulated	Nag(2011)
Edible Films and Coatings for Food Packaging Applications	reducing dehydration (as sacrificial moisture agent), controlling respiration, enhancing product appearance, improving mechanical properties,shelf-life	Senturket al.(2018);Zhouet al.(2020)
Canning food	Texture and color loss prevention from excessive heat processing, browning inhibitor	Yilmaz & Zorba(2010)

1-Application of GDL in dairy products

A- A coagulant

The induced milk proteingelation via GDL is of significantstanding in the acidified products milk processing. GDL utilize for casein micelles coagulation has been reported previously; nevertheless, no preceding studies have performed as proteomic analysis for investigatingindividual milk proteins coagulation. GDL effects on individual caseins coagulation and why proteins areconsidered ascontribution beinga novel. Severalprocesses of production in the industry of dairy need a slow pH declinethroughout manufacturing. In comparison to acidification microbiologically, GDLmight be applied to milk at nearly any temperature and itpermits excellent pH reduction reproducibility and control wherevarious dairy processes need a slow reduction ofpH. GDL is able to be utilized by replacing lactic acid bacteria in cottage cheese production, feta mozzarella and cheese (Rankin et al., 2006). Acidification being direct to form curding is an easy process for controlling compared tobacterial cultureproduction. Also, the production of cheese is faster. Nevertheless, the cultured product of cottage cheese has a better texture and flavor (Makhalet al., 2013).

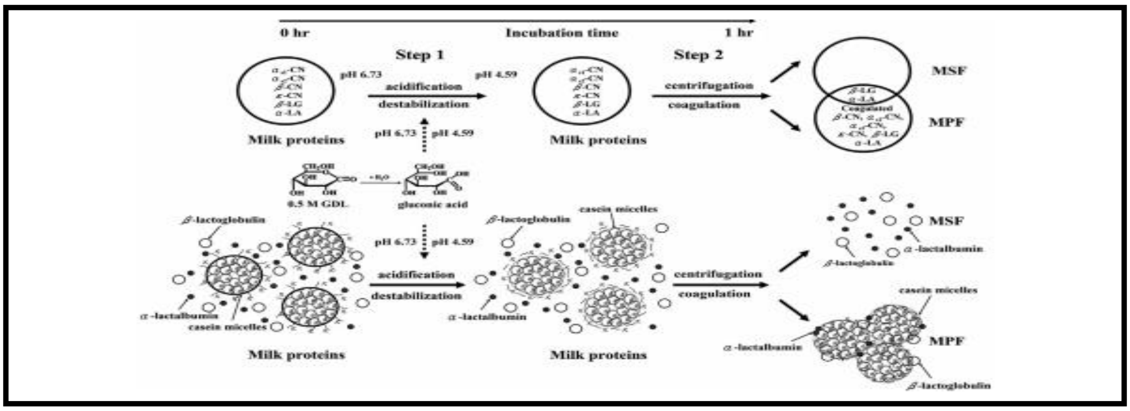


Figure (5): Reaction scheme for GDL effect on the milk proteins coagulation

(Chen et al.,2016)

B- Gelling agent

The acid-induced gelation of Buffalo milk (BM) using GDL was monitored using thromboelastography that can separate gelation into two phases, the onset gelation time and the time to get it firm. The pH at GT ranged from 5.5 to 5.9, which was higher than that reported forcow milk(CM) (pH 5.1–5). The pH at GT of BM increases with an increase in protein content, which may explain the higher pH at GT of BM as compared with CM. Also, the pH of BM at K20 was 5.40–5.65, which was higher than that of CM. Linear relations were found between GT, K20 of BM, and GDL concentration and gelation temperature (Khedka, 2016).

Acid-induced gels made from emulsions with higher protein concentrations had shorter gelation times but higher storage moduli, (G′ and G ″) fracture stresses and strains than gels formed by emulsions with lower protein concentrations. Increasing gelation temperature decreased the gelation time, fracture stresses and strains (Li et al.,2011).GDL is a commonly used as an acidifier. There has also been considerable research about the preparation of

high internal phase emulsions (HIPEs) with various proteins, including gliadingelation using GDL. The HIPEs developed may be useful for encapsulating and delivering bioactive components, such as vitamins or nutraceuticals, through a variety of formats(Zeng, et al., 2017;Liu et al., 2019).

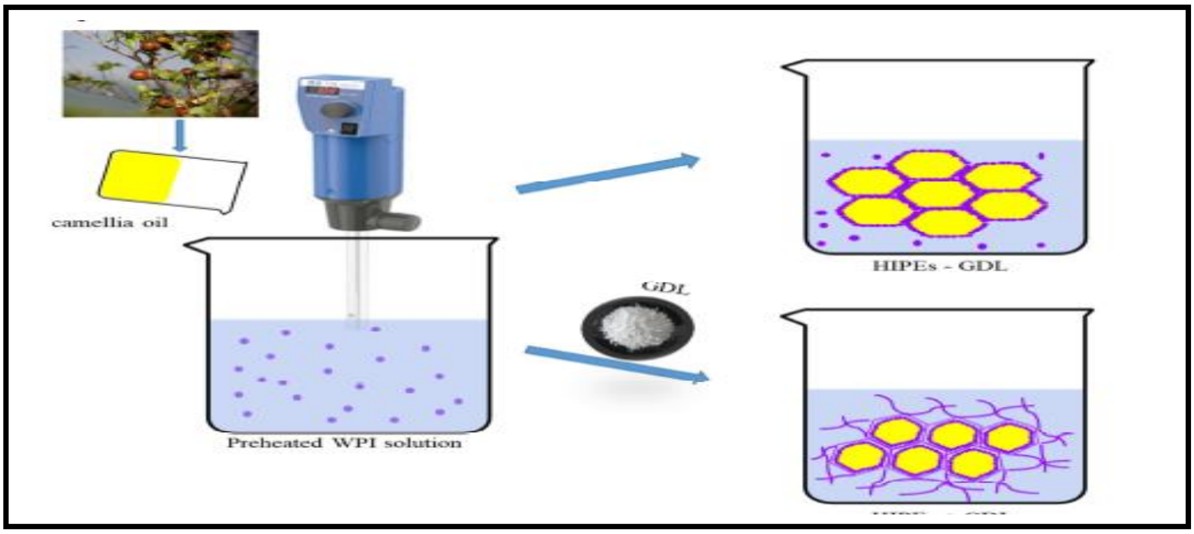


Figure (6): the presence and absence ofGDL (Liuet al., 2019)

2- Application of GDL in Bakery leavening agent

GDL has been utilized for many years in high baking quality mixes for home utilization.GDL stability in dry mixes of a bakery might be enlarged andthe final baked product quality improved viadry GDLcoating, particularly in muffins mixes, bread, cakes, pizza, etc. Simultaneously, the fine-tuning ofCO_2 release rate probabilityviatemperature controlling permitted the GDL incorporation in products of high-tech canned refrigerated dough. Once freezing is not affecting its rising capacity, GDL has also been utilized already for decadesin deep-frozen self-risingcrust pizzas. In recent years, biscuits,finished cakes, andcookiesbesides cereal bars with GDL have beendisplayed on the market.GDL is utilized in bread as an agent of leavening. The produced GA onceH_2O is added reacts with $NaHCO_3$to formCO_2 gas, resulting in the dough rising.In comparisonto other agents of leavening, it is of a slow to intermediate CO_2rate release (Jungbunzlauer, 2008).

GDL is frequently added to mixes of cake due to havingshelf-life being long, and it is often utilized in pastries. Up to 40% extra GDL might be added moreas if is requisite for the reaction with $NaHCO_3$. Suchacidifythe product and preventsmold growth (Feldberg, 1959).GDLslowly hydrolyzedto GA that then reacts with the $NaHCO_3$ to release CO_2 (Figure6). Predominantly interesting is the hydrolysis of GDLslowness at roomtemperature and below, and its hastening with temperature surge: timeof hydrolysisis minimized to half for CO_2 every 10°C temperature raises. Thus, slight acid is producedthroughoutthe preparationof dough and refrigerated storage with the results of a smallloss of CO_2 at such stages(Singer, 2009).

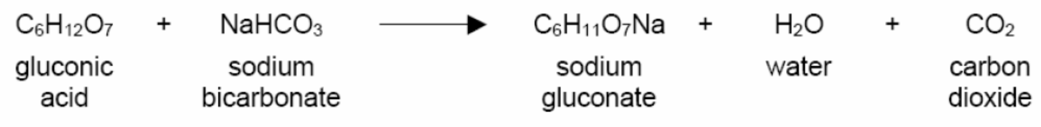


Figure (7):Leavening via GAreaction with $NaHCO_3$

(Singer,2009)

When added into an aqueous solution GDL dissolves rapidly into the medium. Subsequently, it hydrolyses slowly to GA; thus, decreasing the pH progressively and continuously to equilibrium.

3- Application of GDL inConvenience food

Theaddition ofGDL toa mix of udon flour was applied for providing a system of low pH for prolonging the shelf-life of such wheat-based noodles (Sumitraet al., 2006). Nevertheless, the direct acid addition into the system of flour may not be appropriate for noodles as rice-based;noodles ofrice have a short shelf-life because ofretrogradation of starch and microbial risk. Thus, it is mutual that noodles offresh rice mightjust be made obtainable in certain partscloseto the manufacturers. Throughfresh rice noodles dipping in an acidic GDL bath,thenthroughpasteurization in-pack, the quality of the noodles was improved dramatically. The treatment has delayed effectivelythe onset of long termfresh rice noodles retrogradation. Suchdiscoveriescarryexcessive benefits to the manufacturers as the distribution of fresh rice noodles network maybe extended to both existing and new customers(Low et al., 2020).

4- Application of GDL in Meat

GDL addition to processed meat frankfurters control the pH and encourage the ripening and curing process. It permitsreduction up to 30% in the NO_2^-quantity added, and a residual NO_2^- reductionof 75% (Jungbunzlauer, 2008). Nevertheless, ifascorbic acid and GDL were utilized to replace a fewNO_2^- insausages

Turkish fermented, the product had lower production and poorer flavor.Mostly, cooked sausages are cured for developing the characteristics of red color. GDLstimulates the NO_2^- reaction with hemoglobin of meat at a level of little dosage as 0.1to 0.2%, creating the stable cured meat products red color characteristic. Through lowering the pH utilizing GDL, the nitrous acid formation is hastened(Yilmaz and Zorba, 2010;Yimet al.,2015)

5- Application of GDL in Tofu coagulant

The soft-tofu made using GDL in Japan and acetic acid tofu made using acetic acid in Indonesia is mainly that the pH-induced precipitation of soy protein. Acidic whey tofu is considered to be more organoleptically superior to similar commercial products in China because of its special flavor, lightly sweet taste and good texture properties (Watanabe et al., 1997:Qiaoet al., 2010).Soft tofu is frequently utilized in soups. It has an average of 84% as higherH_2O content compared totofu as drier hard. Soft tofu is manufacturedvia coagulants i.e., nigari, $CaCl_2$, or $CaSO_4$, and throughtemperatures adjusting and rates of stirring to make a softer product. H_2O is either out of the pressed curds, or unpressed curds are left (Chang, 2006).

6- Application of GDL in Seafood

GDLaidsin enzymatic browning inhibition in seafood through chelating metalions that enzymes requisite for their activation. It might thus replaceSO_4 as an antioxidant. Combining GDL with SO_4 in the pre-freezingfrozen shrimp'sdip or in the blanching cannedshrimps brine renders it probable to substitute EDTA and minimizethe level of sulfite by 50-90%. Also, GDL is utilized in the cannedshrimps canning brine both as a sorbateand mild acidulant and benzoatepreservative enhancer agent. Moreover, itpermitscanning brine saltlevel reduction by 60-80% with noshrimp firmness loss.Therefore, the shrimps are in good health and have a better clean shrimpflavor, closer to thefresh product(Jungbunzlauer, 2008).

7-Application of GDL in Sauces and dressings

GDL is utilized to help and acidify preserve dressings ofprocessed salad. Its chelating characteristicsaidprotectionversusrancidity ofoil throughions removing which catalyze fats oxidation (PMP, 2004).

8- Application of GDL inBeverages

Due to their unique characteristics, GDL, GA, and sodiumgluconate are the perfectoptimal as potent taste improvers for the industry ofbeverage.Comparing to the intensive standard acids taste i.e.,malic,citric,and lactic acid, GA beingof a slightly sweet, taste of mild acidwith an obstinateeffect on the tongue. GDL, the GAdry form is availablealso. Its taste as mild acid harmonizes verywell with cola, ice tea, exotic and citric fruit aromas.

Sodium gluconate is canminimize the high-intensitysweeteners bitterness such as stevia besidescaffeine and minerals.Moreover, it able to mask off-notes or artificial intensesweeteners aftertaste such asaspartame and saccharin, allowing them to be utilized widelyin low- and mid-calorie soft, energy or sports drinks. The uniquesodium gluconate characteristics qualify it as an alternative select forbetter and healthier tasting beverages.Drinks as soft made by simple ingredients blending, and hence with high throughput, the pH stabilization can take too long if utilizingGDL(Singer, 2011).

Conclusion

The study showed positive benefits of using GDL in molecular manufacturing. For example, it has been used in the dairy products to build a gelatinous network and then coagulants, in addition, improving the quality of baked products because GDL is considered as a fluffy agent. It also showed that GDL can successfully prevent the growth of microorganisms and thus prolonging the shelf life of food. The studies also showed its ability to improve the characteristics of other food products such as sauces, seafood, salads and drinks.

References

- Anonymous(1981). Evaluation of the health aspects of glucono-delta-lactonoe as a food ingredient. Report, Bureau of Foods, Food and Drug Administration, Department of Health and humanServices, Washington, USA. SCOG 11-11, Contract No. FDA 223-78-2100, 19 p.
- Anonymous.(2020). Supporting g Information for Low-Priority Substance D-GA, .delta.-Lactone (CASRN 90-80-2)
- (Glucono-delta-lactone Final Designation. Office of Pollution Prevention andToxics. U. S. Environmental Protection Agency. Washington, USA.129.
- Bankar, S. B. M. V. Bule, R. S. Singhal and L.(2009).Ananthanarayan, Biotechnol. Adv. , 27, 489–501
- Barringer, S.A., J. A. Ali, H.J. Chung. (2005). “Electrostatic Powder Coating of Sodium Erythorbate and GDL to Improve Color and Decrease Microbial Counts on Meat.” Inn. Food Sci. Emerg. Technol.6: 830 189-193.
- BeMiller, J. N. 1992. Carbohydrates, in Kirk-Othmer Encyclopedia of Chemical Technology, Fourth Edition, Vol. 4, Pp. 911-948.
- Bertelsen G, Fabech B, Møller AJ, Andersen HJ, Ipsen R, Friis J (1995) Additives and other ingredients in Danish meat products. In The Use of Additives in Meat Products throughout Europe (Honikel KO, Ed.). The Hague: ECCEAMST, CIP-Data KoninklijkeBibliotheek, pp. 178–196.
- Chang, K.C. (2006). “Chemistry and Technology of Tofu Making.” In: Y.H. Hui ed. Handbook of Food Science, Technology, and Engineering, Vol. 4 (Boca Raton: CRC/Taylor and Francis), Pp. 171-1 to 171-24.

- Chen, Y. C., Chen, C. C., Chen, S. T., & Hsieh, J. F. (2016). Proteomic profiling of the coagulation of milk proteins induced by glucono-delta-lactone. Food Hydrocolloids, 52, 137-143.
- Feiner,G.(2016).Additives.In:Salami. Practical Science and Processing Technology. Feiner,G(Ed.),Chapter4,Academic Press, London United Kingdom. Pp.: 59-88.
- Feldberg, C. "The Use of GDL in Bakery Products." The Bakers Digest October (1959):46- 49.
- Haynes, W. M. (2010). Handbook of chemistry and physics (9thEd.). Boca Raton, Florida: CRC Press4–58.
- Juncher D, Vestergaard CS, Søltoft-Jensen J, Weber CJ, Bertelsen, Skibsted LH (2000) Effects of chemical hurdles on microbiological and oxidative stability of a cooked cured emulsion type meat product. Meat Science, 55 (4), 483–491.
- Jungbunzlauer. 2008. "GDL: Uniqueness in Acidification." Jungbunzlauer Factsheet, Jungbunzlauer, Basel, Switzerland. 5 Pp.
- Khedkar, C.D; Kalyankar, S.D; Deosarkar,S.S.(2016). Buffalo Milk. Encyclopedia of Food and Health., PP; 522-528
- Kim, S; Thiessen, PA; Bolton, EE; Chen, J; Fu, G; Gindulyte, A; Han, L; He, J; He, S; Shoemaker, BA; Wang, J; Yu, B; Zhang, J; Bryant, SH. (2016). PubChem Substance and Compound databases. 44: D1202-D1213.
- Leskovac,.V. S. Trivić, G. Wohlfahrt, J. Kandrač&Peričin, D. (2005). Int. J. Biochem. Cell Biol., 37: 731–750.
- Li, F., Kong, X., Zhang, C., & Hua, Y. (2011). Rheological properties and permeability of soy protein-stabilised emulsion gels made by acidification with glucono-δ-lactone. Journal of the Science of Food and Agriculture, 91(12), 2186-2191.
- Liu, W., Gao, H., McClements, D. J., Zhou, L., Wu, J., & Zou, L. (2019). Stability, rheology, and β-carotene bioaccessibility of high internal phase emulsion gels. Food hydrocolloids, 88, 210-217.
- Low, Y. K., Esah, E. M., & Cheng, L. H.(2020). The impact of glucono-delta lactone (GDL) on rice flour pasting properties and GDL's dipping effects on the quality of rice noodles. Journal of Food Processing and Preservation, 3(45):e14944.
- Kornecki, J. F., Carballares, D., Tardioli, P. W., Rodrigues, R. C., Berenguer-Murcia, Á., Alcántara, A. R., & Fernandez-Lafuente, R. (2020). Enzyme production of D-GA and glucose oxidase: successful tales of cascade reactions. Catalysis Science & Technology, 10(17), 5740-5771.
- Makhal, S., S.K. Kanawjia and A. Giri. "A Dual Acidification Process for the Manufacture of Direct Acidified Cottage Cheese." Intl. J. Dairy Technol. 66, No. 4 (2013): 552-560.

- Nag, A. (2011). Development of a microencapsulation technique for probiotic bacteria Lactobacillus casei 431 using a protein-polysaccharide complex: a thesis presented in partial fulfillment of the requirements of the degree of Masters of Technology in Food Technology at Massey University, Palmerston North, New Zealand (Ph.D.Dissertation, Massey University).
- Nagarajan, V. 1992. Genetic Engineering (Microbes), in Kirk-Othmer Encyclopedia of Chemical Technology, Fourth
- PMP (PMP Fermentation Products). 2004. "Glucono Delta Lactone." PMP Factsheet, PMP Fermentation 943 Products, 900 NE Adams St., Peoria, IL 61603. 7 Pp.
- Qiao, Z., Chen, X. D., Cheng, Y., Liu, H., Liu, Y., & Li, L. (2010). Microbiological and chemical changes during the production of acidic whey, a traditional Chinese tofu-coagulant. International Journal of Food Properties, 13(1), 90-104.
- Ramachandran, S., Fontanille, P., Pandey, A., &Larroche, C. (2006).GA: Properties, applications and microbial production. Food Technology & Biotechnology, 44 : (2)185-195.
- Rankin, S.A., C.M. Chen, D. Sommer et al. 2006. "Mozzarella and Scamorza Cheese." In: Y.H. Hui ed. Handbook of Food Science, Technology, and Engineering, Vol. 4 (Boca Raton: CRC/Taylor and Francis), Pp. 150-1 to 150-11.
- Rubico, S.M. and M.R. McDaniel. "Sensory Evaluation of Acids by Free-Choice Profiling." Chem. Senses 17, no. 3 (1992): 273-289.Singer, R. (2009). Glucono-delta-Lactone (GdL) A Natural Way of Leavening.Technical White Paper presented by Jungbunzlauer.9.
- Samelis, J., Bedie, G. K., Sofos, J. N., Belk, K. E., Scanga, J. A., & Smith, G. C. (2002). Control of Listeria monocytogenes with combined antimicrobials after postprocess contamination and extended storage of frankfurters at 4 C in vacuum packages. Journal of Food Protection, 65(2), 299-307.
- Singer, R. (2011). New ways for beverage formulators to reduce bitterness and balance sourness. Technical White Paper presented by Jungbunzlauer, 12.
- Søltoft-Jensen, J., & Hansen, F. (2005). New chemical and biochemical hurdles. In: Emerging technologies for food processing (Pp. 387-416). Academic Press.
- Senturk P, T., Müller, K., & Schmid, M. (2018). Alginate-based edible films and coatings for food packaging applications. Foods, 7(10), 170.
- Sumitra, R., Pierre, F., Ashok, P., & Christian, L. (2006). GA: Properties, applications and microbial production. Food Technol Biotechnol, 44(2), 185-195.
- U.S. EPA. (2019). Estimation Programs Interface Suite, v 4.11. United States Environmental Protection Agency, Washington, DC, USA.
- U.S. EPA. (2019). Estimation Programs Interface Suite, v 4.11. United States Environmental.

- Watanabe, T., Ed. Science of Tofu. Food Journal Co., Ltd., Kyoto, Japan, 1997; 126–127 Wong, C.M., K.H. Wong and X.D. Chen.(2008)"Glucose Oxidase: Natural Occurrence, Function, Properties, and IndustrialApplications." Appl. Microbiol. Biotechnol. 78: 927-938.
- Wong, C.M., K.H. Wong and X.D. Chen. "Glucose Oxidase: Natural Occurrence, Function, Properties, and Industrial Applications." Appl. Microbiol. Biotechnol. 78 (2008): 927-938.
- Yim, D. G., Jang, K. H., & Chung, K. Y. (2015). Effect of GdL addition on physico-chemical properties of fermented sausages during ripening. Korean Journal for Food Science of Animal Resources, 35(3), 322.
- Yilmaz, M.T. and Zorba O.(2010). "Response Surface Methodology Study on the Possibility of Nitrite Reduction byGlucono Delta Lactone and Ascorbic Acid in Turkish Type Fermented Sausage (Sucuk). J. Muscle Foods 21: 15-30.
- Zeng, T., Wu, Z. L., Zhu, J. Y., Yin, S. W., Tang, C. H., Wu, L. Y., & Yang, X. Q. (2017). Development of antioxidant Pickering high internal phase emulsions (HIPEs) stabilized by protein/polysaccharide hybrid particles as potential alternative for PHOs. Food Chem, 231,122-130
- Zhou, S., Jin, T., Sheen, S., Zhao, G., Liu, L., Juneja, V., & Yam, K. (2020). Development of sodium chlorite and GDL incorporated PLA film for microbial inactivation on fresh tomato. Food Research International, 132, 109067.