Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

Preparation and evaluation of novel Saltiness taste contrast system using water in oil in water double emulsion

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ABSTRACT

Due to the close relationship between high salt consumption and the increasing prevalence of high blood pressure and cardiovascular disease in the world, the food industry is trying to createfoods that better align with consumer expectations regarding sodium reduction. In this study, the strategy of taste contrast technique through salt encapsulation in the internal aqueous phase of the water-in-oil-in-water double emulsion ($W_1/O/W_2$) was investigated as a novel technological approach for sodium reduction. To this end, different concentrations of salt (0, 0.5, 0.75, and 1%) and cinnamaldehyde (1%) as an antioxidant agent were used in the internal aqueous phase and the oil phase of the double emulsion, respectively. In order to investigate emulsion stability, encapsulation efficiency, and salt release behavior, the oil phase was fabricated in two liquid and solid states in the form of oleogel. The characteristics of the produced emulsions were investigated in terms of storage stability, heat and freezing stability, color, oxidation, encapsulation efficiency, viscosity, rheology, and morphology. The emulsion sample containing gel network in the oil phase and 0.75% salt in the internal aqueous phase was the best sample in terms of stability and rheological behavior.

ARTICLE INFO

Article History:

Received 2022/ 07/ 13
Accepted 2023/ 01/ 19

Keywords:

Double emulsion,
Salt reduction,
Taste contrast system,
Saltiness perception,
Oleogel.

DOI: **10.22034/FSCT.19.132.281**
DOR: **20.1001.1.20088787.1401.19.132.21.4**

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1. Introduction

According to dietary recommendations, excessive consumption of sodium with the presence of salt as the main source of sodium in human food has become an epidemic risk in the world. The use of salt water or salt powder with a high concentration in different food products, on the one hand to control the growth of undesirable microorganisms and on the other hand to create a pleasant flavor, has caused the risk of high blood pressure, cardiovascular diseases and Kidney dysfunction will increase [1]. This has led to more consumer demand for low-sodium food products, and the food industry must move to reduce salt in food products to meet consumer expectations. Although various strategies have been proposed to reduce salt in food products, still the average amount of salt consumption in the world exceeds the recommended limit of 5 grams per day, equivalent to the daily intake of 2 grams of sodium, by the World Health Organization [2]. The multipurpose role of salt increases the complexity of reducing sodium in the diet, and in addition, salt reduction solutions should be designed without creating sensory perception in consumers and subsequently reducing product acceptance. Since the release of taste from any food texture is the first and most important step to understand it by human senses and thus help to accept the product by the consumer, removing, reducing or replacing salt in food formulations is simply not possible and researches in this field to be continued.

Among the solutions proposed to reduce the amount of sodium intake, we can gradually and step by step reduce the concentration of salt, use the method of replacing sodium chloride salt with calcium, lithium, magnesium and potassium chloride salts, adjusting the size of salt crystals and the heterogeneous distribution of salt in solid foods. The technique of taste contrast to reduce the concentration of sodium chloride salt in food formulations without affecting the intensity of taste perception and the new method of taste contrast technique by encapsulating salt in the internal aqueous phase of the double emulsion of water in oil in water ($W_1/O/W_2$) and its sudden release in the mouth [3-5]. Among the above methods, the technique of flavor contrast with salt encapsulation has received much attention in recent years because there is no need to change the production method or to prepare different production equipment, and the encapsulated salt can be easily combined with other food additives at any stage. added to the formulation. However, the determining factor for the success of these systems in the design of low-salt foods is the optimization of the formulation in terms of the volume of phases, salt concentration, type and concentration of emulsifiers and emulsion rheology characteristics [6 and 9]. For this reason, in order to use this technique in real food formulations, and not in food models, there are still challenges and more research is needed. In this context, Kasprzak et al. (2019) produced stable water-in-oil-in-water emulsions containing internal saline solution using waxy rice starch modified by a non-chemical method and modified with octenyl succinic anhydride (OSA), as a control sample. and investigated the release of salt during the emulsion destabilization process caused by amylase activity in the mouth [2]. The results of this study showed that the efficiency of this salt reduction approach for modified waxy rice starch was increased compared to emulsions stabilized with OSA modified starch. Sensory evaluation on tomato soup, to validate this salt reduction approach for a real food model, showed that a 25% reduction in salt compared to current UK products is well feasible. In 2018, Devanthi et al. also used double emulsion $W_1/O/W_2$ for yeast encapsulation and consecutive inoculation*Zygosaccharomyces roxy*and studied the salt-loving Tetragenococcus in Muromi during the fermentation of soy sauce, in which the amount of sodium chloride was reduced or replaced with potassium chloride salt [7]. The use of double emulsion led to the production of morami with microbiological and physicochemical characteristics similar to the sample containing high salt. On the other hand, Morumi with reduced salt had the same aroma characteristics as the aroma obtained from the standard sample, which indicates the possibility of producing low-salt soy sauce without reducing its quality. In another study by Chiu et al. (2017), sodium (salt) in the internal water phase of food emulsions $W_1/O/W_2$ Stabilized

with starch particles, it was coated with the aim of increasing the perception of the intensity of salty taste [8]. The results of this study showed that while increasing the levels of OSA treatment increases the stability of the emulsion, medium or low levels of starch modification will lead to an increase in salinity. Therefore, modified starch with 1.5% OSA for sodium delivery and with 2% OSA for sodium delivery was suggested in systems that require more process stability. Also, Noort et al. (2012) reported that the method of flavor contrast in bread with salt coating can increase the perception of saltiness, and by this means they reduced the amount of salt by 50% while maintaining the desirable sensory characteristics of bread [9].

Therefore, according to the existing studies in the field of reducing salt consumption, the use of taste contrast to reduce the taste content while maintaining the intensity of the taste is considered an important achievement. Based on the studies, the effect of the physical state of the oil phase in the double emulsion on the behavior of the encapsulated salt has not been reported so far. Based on this, the aim of this study was to investigate the effect of the gelation of the oily phase in the water-in-oil-in-water double emulsion in order to design a new flavor discrimination system, which can be used to reduce the salt content in the internal aqueous phase of the emulsion, to increase the flavor intensity. Maintained optimal salinity. In addition, cinnamaldehyde as a natural oxidant compound was encapsulated in the oil phase of the emulsion and the oxidation stability of the salt delivery systems was also investigated.

2- Materials and methods

Sunflower liquid oil (Frico, Iran), cinnamaldehyde (Merck, Germany), PGPR (Denisco, Denmark), monoglyceride (Henan, China) were purchased. Other chemicals used were prepared with laboratory grade.

2-1-Production of salty taste discrimination system

Making a double emulsion by a two-step method and by re-emulsifying the initial water-in-oil emulsion (W_1/O) was done and 8 different formulas were prepared according to Table 1 and Figure 1. In order to investigate the effect of the physical state of the oil phase on the behavior of salt release from the emulsion structure, liquid sunflower oil and once structured oil gel or oleogel were used in emulsification. On the other hand, in order to compare the effect of salt coating on the perception of salty taste during sensory evaluation, samples with the presence of free salt in the external aqueous phase were also designed as a control, according to Table 1. In order to investigate the effect of cinnamaldehyde on the oxidation process, this compound was included in the oil phase of the emulsions.

For this purpose, first the primary emulsion is prepared by adding the aqueous phase containing salt to the oily phase containing PGPR emulsifier and cinnamaldehyde at 70 degrees Celsius while continuously stirring at 500 rpm for 15 minutes. Then, the ultrathorax device was used at 15,000 rpm for 2 minutes and 10,000 rpm for another 2 minutes for homogenization and production of primary emulsion with uniform particle size. In the production of samples containing oleogel, monoglyceride (MG) gelling compound was used in the oily phase, and to dissolve it, the oily phase was heated for 10 minutes at 70 degrees Celsius. To prepare the secondary emulsion, the primary emulsion, after reducing the temperature to 40 degrees Celsius, gradually changes to the external aqueous phase (W_2) containing starch emulsifier modified with OSA with the removal of side branches (4%), was added while stirring at 800 rpm, and then secondary homogenization was performed by an ultrathorax device at 13,000 rpm for 2 minutes and 10,000 rpm for 2 minutes. became Control samples without salt and essential oil were also formulated according to Table 1. All samples were stored at 4 degrees Celsius after production and their characteristics were examined during 14 days of storage.

Table 1 Formulation and production conditions of produced double emulsion samples

			IN_1		O			IN_2		
	Sample	Oil type	Water (g)	Salt (g)	Oil (g)	PGPR (g)	MG (g)	Water (g)	Modified starch (g)	Salt (g)
1	1% salt in external	Liquid	20	-	74	6	-	137.5	10	2.5
2	1% salt in internal	Liquid	17.5	2.5	74	6	-	140	10	-
3	0.75% salt in internal	Liquid	18.125	1.875	74	6	-	140	10	-
4	0.5% salt in internal	Liquid	18.75	1.25	74	6	-	140	10	-
5	1% salt in external	Solid	20	-	66	6	8	137.5	10	2.5
6	1% salt in internal	Solid	17.5	2.5	66	6	8	140	10	-
7	0.75% salt in internal	Solid	18.125	1.875	66	6	8	140	10	-
8	0.5% salt in internal	Solid	18.75	1.25	66	6	8	140	10	-

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.

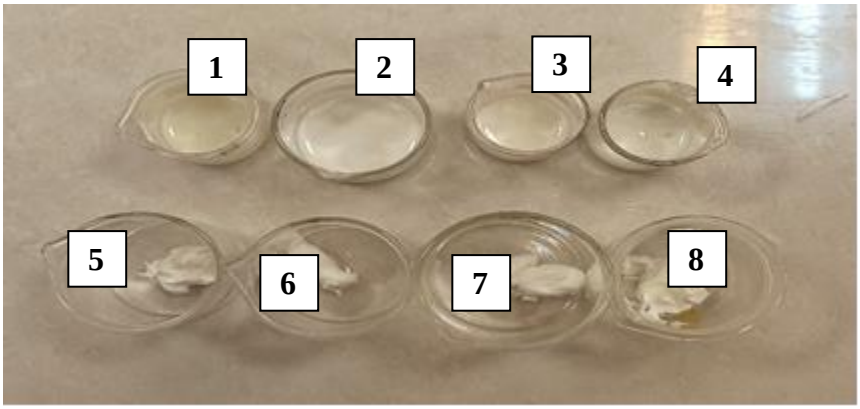

Fig 1 Appearance of double emulsion samples
1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.

2-2- Examining the characteristics of double emulsions

2-3-Stability during the maintenance period

In order to measure the stability, 5 ml of the emulsion sample was poured into a 15 ml falcon, and then it was centrifuged at 1500 rpm for 15 minutes at a temperature of 4 degrees Celsius, and the amount of separated water was measured

during 7 days of storage and the amount of water on It was reported as a percentage.

2-4- Accelerated stability during freezing and thawing

In order to investigate the accelerated stability, five freeze-thaw cycles were used. The samples were frozen in a freezer at minus 20 degrees Celsius for 15 minutes and then defrosted at 70 degrees Celsius for 15 minutes. After the end of the fifth cycle, the apparent stability of the samples was checked visually in terms of any color change, phase separation and hydration.

2-5-Stability against heat

In order to check the effect of the thermal process, the samples were heated in an oven at 100 and 150 degrees Celsius (in the same temperature conditions as hamburger frying conditions) for 10 minutes, and then the apparent stability of the samples in terms of any color change, phase separation, and dehydration visually Checked out.

6-2-color measurement

Color measurement was done by digital photography in a box with dimensions of 50x50x60 (length, width and height) under controlled conditions. The inner walls of this box were covered with white A4 paper, and a Cixing low-power lamp (60 W) was used to provide the necessary light for taking pictures. After photographing the samples with a camera, color analysis was done using Photoshop software. The color parameters of the samples include brightness (L^*), redness/greenness (a^*) and yellow/blue (b^*) was measured by digital photography method. The samples were photographed using a Canon digital camera (14 MP, Tokyo, Japan).

2-7-primary oxidation

Primary oxidation of emulsion samples was investigated by measuring peroxide value (PV). One of the most common methods of measuring the spoilage of edible oils is to determine the peroxide number. Although hydroperoxides are divided into volatile and non-volatile compounds, but calculating the amount of peroxide is a suitable method to estimate the amount of oil oxidation. For this purpose, first, 0.3 g of sample was added to 1.5 ml of chloroform/methanol mixture (1:1, volume: volume) to extract the lipid phase, and it was mixed well for 1 minute, and then at 3000 rpm for It was centrifuged for 5 minutes. 100 microliters of clear chloroform layer with 4.9 ml of chloroform/methanol mixture (7:3, volume:volume) and 30 microliters of Fe thiocyanate solution.$^{2+}$ was mixed (this solution was produced by mixing 25 microliters of ammonium thiocyanate solution (3.94 M) with 25 microliters of iron solution (0.072 M). This iron solution was mixed from the supernatant of 25 milliliters of barium chloride solution (0.132 M), 25 ml of ferrous sulfate (0.144 M) and 0.1 ml of hydrochloric acid (10 M) were obtained.After incubation at room conditions for 20 min, the absorbance at 500 nm was compared to a control sample, containing all reactants. Except for the target sample, it was measured using a spectrophotometer (Spec1650PC, Shimadzu, Osaka, Japan). The results were presented in milliequivalents of oxygen per kilogram of oil of the samples [10].

8-2-secondary oxidation

The measurement of reactive substances with thiobarbituric acid was performed based on the method reported by Cui et al. in 2018 [11]. Thiobarbituric acid reagent was prepared by mixing 0.84 grams of thiobarbituric acid, 37.5 grams of trichloroacetic acid, 4.4 milliliters of hydrochloric acid (12 M) and 207 grams of distilled water. Then 50 ml of the prepared thiobarbituric acid reagent was added to 1.5 ml of ethanol containing 2% of butyl dehydroxytoluene. After that, an equal volume of this solution was completely mixed with the respective samples. The mixture was heated at 100°C for 30 minutes, then cooled to 25°C and centrifuged at 2000 rpm for 5 minutes. The supernatant was collected and its absorbance was measured at a wavelength of 532 nm. The amount of reactive substances with thiobarbituric acid was calculated according to the standard curve of malondialdehyde.

9-2-Rheology

The rheological behavior of samples 4, 5 and 8 was studied using MCR-302 rotational viscometer. A Peltier system (Viscotherm VT2, Phar Physica) was used to control the

temperature of the bottom plate. Strain scan test[1] In a fixed frequency of 1 Hz, temperature of 25 degrees Celsius and shear strain range of 0.01-100%, it was done to obtain the linear viscoelastic range. Frequency scan test[2]It was done in the range between 0.01 and 100 radians/s with a constant stress range in the linear viscoelastic range at a temperature of 25 degrees Celsius. Temperature ramp test[3]It was performed at a temperature between 20 and 100 degrees Celsius in the linear viscoelastic range and at a frequency of one Hz. Calculations of the drop or viscous modulus (G''), storage or elastic modulus (G'), loss modulus (tan δ) and complex viscosity ($^{*}\mu$) were calculated and compared from the resulting graphs [12].

2-10- Method of data analysis

All experiments were carried out in the form of a completely random design and at least three repetitions of the design. The obtained data were reported based on the mean ± standard deviation. The average of the results using the variance analysis method and at a significant level ($0.05P<$) was analyzed. Means were compared with Duncan's multiple range test and SAS software.

3. Results and Discussion

3-1-Stability during the maintenance period

The stability results during the storage period by measuring the percentage of aqueous phase separated by centrifugation are reported in Table 2. Centrifuging is a separation technique that is used in the phase separation of dispersions, emulsions and other formulations in many industries. All the samples, except for sample 1, showed good stability against thermodynamic instabilities during one week of storage, and no signs of biphasing and dewatering were observed in them after centrifugation. This indicated the success of the formulation and method of producing double emulsions. The presence of salt in the internal aqueous phase in all three concentrations of 0.5, 0.75 and 1% (samples 2, 3 and 4) by balancing the Laplace pressure difference between the droplets of the initial water-in-oil emulsion, as well as maintaining the balance in the osmotic pressure difference Between the internal and external water phases, it played an important role in preventing the merging of water droplets and thus the instability of the samples [13]. In addition, it has been reported that the presence of salt in an appropriate concentration in the internal aqueous phase of double emulsions improves the efficiency of the emulsifier by increasing the absorption of the emulsifier at the oil/water interface and reducing the surface tension in the initial water-in-oil emulsion droplets, leading to long-term stability. The duration of samples even under the influence of centrifugal force helps [14]. In samples 6, 7 and 8, in addition to the presence of salt in the internal aqueous phase, the creation of a gel network in the oil droplets leads to an increase in viscosity (which will be explained later) and a decrease in the droplet movement speed, and subsequently the possibility of the internal aqueous phase droplets merging or the globules merging Reduced fat, accumulation and gravitational separation. Ghiathi et al. (2021) also reported similar results in their study regarding the effect of the physical state of the internal water phase and oil phase of double emulsions [10]. The effect of the gelation of fat globules in the initial water-in-oil emulsion droplets has led to the stability of sample 5 by improving the viscoelastic properties. On the contrary, in sample 1, due to the low viscosity and weak viscoelastic properties of the system, the integration of water droplets in the oil led to the separation of 31-42% of the aqueous phase during centrifugation.

1. Stress sweep test
2. Frequency sweep test
3. Temperature ramp test

Table 2 Storage stability of taste contrast systems

Sample number	Storage (d)			
	1	2	4	7
1	100.00±0.00Aa	42.09±1.68Bb	35.63±1.51Bc	31.90±0.95Bd
2	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
3	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
4	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
5	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
6	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
7	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa
8	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa	100.00±0.00Aa

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.
*Data represent mean ± standard deviation of three independent repeats.
**Different capital letters in each column and lowercase ones in each row indicate significant differences ($P < 0.05$).

2-3- Accelerated stability during freezing and thawing

Since two-phase systems are usually prone to physical instabilities, the accelerated stability of double emulsion formulations was studied. As shown in Table 3, all samples containing solid fat in the oil phase (samples 5, 6, 7 and 8) showed excellent resistance to 5 cycles of freezing and thawing and showed no signs of oil-water separation. And the destruction of the samples was not observed. This stability is caused by the creation of strong intermolecular connection areas between the gelling molecules in the oil phase, which leads to the creation of a 3D and integrated oleogel network [15] and improves the stability of the whole system to temperature stress. Similar results have been reported by Ghiathi et al. (2021) on the effect of the physical state of the oily phase in the structure of double emulsions [10]. Samples 3 and 4 containing liquid oil and a low percentage of salt encased in the internal phase did not show relative stability, and evidence of oil separation was observed at the end of the third freezing-thawing cycle, which was caused by the low resistance of the liquid fat globules against It was temperature stress. The most unstable sample was sample 1, followed by sample 2, which showed signs of instability from the end of the first freeze-thaw cycle. This result showed a significant effect of the physical state of the oil phase of the double emulsion on the stability of the system, and as a result, a protective effect on the optimal concentration of the encapsulated salt in the internal aqueous phase.

Table 3 Freeze-thaw stability of taste contrast systems

Sample number	Stability against 5 cycle freeze-thaw				
	1	2	3	4	5
1	Unstable	Unstable	Unstable	Unstable	Unstable
2	Slightly Oil Separation	Slightly Oil Separation	Unstable	Unstable	Unstable
3	Stable	Stable	Slightly Oil Separation	Slightly Oil Separation	Unstable
4	Stable	Stable	Slightly Oil Separation	Slightly Oil Separation	Unstable
5	Stable	Stable	Stable	Stable	Stable
6	Stable	Stable	Stable	Stable	Stable
7	Stable	Stable	Stable	Stable	Stable
8	Stable	Stable	Stable	Stable	Stable

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.

3-3-Stability against heat

The results of the thermal stability of the samples at two different temperatures are reported in Table 4. Sample 1 was completely unstable at both studied temperatures. At a temperature of 100 degrees Celsius, samples 2, 3

and 4 were completely stable and no signs of water-logging and accumulation of fat globules were observed on the surface of the sample. In samples 5 to 8, while applying heat, the viscosity of the system decreased drastically and the samples changed from semi-solid to liquid. However, the double emulsion remained stable and no phase separation was observed. On the other hand, at a higher temperature (150 degrees Celsius), sample number 1 became unstable, and the other samples remained only as an oily phase after evaporating most of their aqueous phase.

Table 4 Heat stability of taste contrast systems

Sample number	**Heat stability**	
	100 °C for 10 min	150 °C for 10 min)
1	Unstable	Unstable
2	Stable	Evaporation of water
3	Stable	Evaporation of water
4	Stable	Evaporation of water
5	Stable with change to liquid	Evaporation of water
6	Stable with change to liquid	Evaporation of water
7	Stable with change to liquid	Evaporation of water
8	Stable with change to liquid	Evaporation of water

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.

3-4-color

In colorimetric studies, no significant difference was observed between brightness, red-green, and blue-yellow parameters of samples containing different concentrations of salt in the internal aqueous phase (Table 5). As a result, the overlap of different concentrations of salt in the internal aqueous phase and also The physical properties of the oily phase in these samples did not have much effect on the color of the emulsions. Although in the sample containing liquid oily phase and 1% salt in the external phase, more yellowness and less brightness were observed. This can be caused by the relative instability of this sample compared to other samples and the accumulation of oil droplets on the surface of the sample that has been photographed.

Table 5 Color properties of taste contrast systems

Sample number	***L****	***a****	***b****
1	86.67±0.58B	2.00±1.00A	25.00±1.00A
2	89.33±1.53A	2.00±1.00A	17.00±1.00B
3	89.67±1.53A	2.33±1.15A	17.00±1.00B
4	89.67±1.15A	2.00±1.00A	16.33±0.58B
5	89.67±1.53A	1.67±1.15A	17.67±0.58B
6	89.00±1.00A	2.33±1.15A	17.00±1.00B
7	90.67±0.58A	2.00±1.00A	17.33±1.15B
8	89.00±1.00A	2.00±1.00A	17.00±1.00B

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.

*Data represent mean ± standard deviation of three independent repeats.

**Different capital letters in each column indicate significant differences ($P < 0.05$).

3-5-oxidation

Table 6 shows the results related to peroxide number and reactive substances with

thiobarbituric acid in fresh samples of double emulsion. The reported values indicated good oxidative stability of the samples and no significant production of products resulting from primary and secondary oxidation. In addition, no significant difference was observed between the oxidation stability of the samples. The reason for this was keeping the amount of oily phase constant and the thermal profile similar in all samples. It is also important to mention that the process of oleogel production in the oil phase of double emulsions is a physical modification and occurs without changing the composition and chemical properties of fatty acids and only by adding the appropriate amount of gelling compound. Therefore, no chemical interactions have occurred between the different components of the oleogel, and the gel is created as a result of molecular self-assembly. For this reason, due to the non-change of fatty acid profile, no difference was observed between the oxidation of samples containing liquid oily phase and oily gel [16].

Table 6. Peroxide and TBARS of taste contrast systems

Sample number	PV (Meq O_2/kg oil)	TBARS (mg malondialdehyde/kg oil)
1	0.82±0.06A	0.33±0.09A
2	0.74±0.07A	0.28±0.07A
3	0.81±0.06A	0.35±0.08A
4	0.76±0.09A	0.29±0.08A
5	0.73±0.07A	0.37±0.08A
6	0.76±0.06A	0.28±0.08A
7	0.78±0.07A	0.37±0.05A
8	0.75±0.07A	0.32±0.08A

1) 1% salt in W_2 + liquid oil, 2) 1% salt in W_1+ liquid oil, 3) 0.75% salt in W_1+ liquid oil, 4) 0.5% salt in W_1+ liquid oil, 5) 1% salt in W_2 + solid oil, 6) 1% salt in W_1+ solid oil, 7) 0.75% salt in W_1+ solid oil, 8) 0.5% salt in W_1+ solid oil.
*Data represent mean ± standard deviation of three independent repeats.
**Different capital letters in each column indicate significant differences ($P < 0.05$).

3-6-Rheology

The results of the strain scan test, in order to check the linear viscoelastic range of the samples and the amount of critical strain at the intersection of the elastic and viscous modulus, are shown in Figure 2. In all the samples, G' Initially greater than G'' was, which indicated a dominant gel-elastic behavior in the samples. Although, samples 5 and 8, having a gel-oil phase, showed much higher values of elastic and viscous moduli than sample 4 in the entire stress range of the study. This indicated the stronger internal structure and more viscoelastic properties of double emulsions with the presence of oleogel network, which confirms the high thermodynamic stability of these samples compared to the normal double emulsion structure. The presence of salt in the aqueous phase compared to the external aqueous phase did not have a significant effect on the amount of elastic moduli and viscous samples. This result shows that the rheological properties of the designed double emulsions are more influenced by the physical state of the oil phase than the location of the salt. These findings agree with previous reports about the strong dependence of the rheological behavior of colloidal structures on the physical state of the phases [10 and 12]. On the other hand, the intersection point G' And G'' which was equivalent to the critical strain of the samples, for samples 5 and 8 it was significantly higher than sample 4, which indicated lower shear sensitivity and higher mechanical strength of the double emulsion with the presence of an oily gel network. Beyond the intersection point of the modules, the phase transition from a solid gel state to a viscous liquid was observed for all samples, with higher values G'' It was evident (Figure 2).

Figure 3 shows the results of the frequency scan test. Samples 5 and 8 showed weaker frequency-

dependent behaviors than sample 4 because both curvesG' And G''Very slight positive slopes even had high oscillation frequencies. According to Figure 3, the values of the elastic modulus in the entire frequency range studied for all samples were higher than the viscous modulus. Therefore, the absence of intersection points between storage and loss modulus confirmed their dominant solid elastic characteristic [12]. On the other hand, in all the studied frequency range,G' AndG'' In the samples containing the oily gel network, there was more oil than the sample containing the liquid oily phase, which was in line with the strain scan test results and confirmed the stronger viscoelastic properties of samples 5 and 8. In addition, the placement of salt in the entire frequency range did not have a significant effect on medulviscosity and elasticity. The values of the loss modulus (tan δ) for all samples were between 0-1.1 (Figure 3), which was evidence of the gel-like structure in them. Although in samples 5 and 8 with increasing frequency, tan δ values remained close to 0.1, which showed the structural similarity of these samples to real gel.

The temperature ramp test was performed to evaluate the rheological behavior of the samples under the influence of temperature increase up to 100 degrees Celsius. Figure 4 Strong temperature dependent behaviorG' AndG'' It shows in examples 5 and 8. At low temperatures, the elastic modulus was higher than the viscous modulus, and as the temperature increased, the values of both modulus decreased, however, the decreaseG' faster thanG'' and led to the creation of a cross point in the temperature range of 55-70 degrees Celsius, which indicated the change of behavior from gel to sol [17]. At this point, the rapid destruction of intermolecular interactions in the oleogel phase has started due to the melting of monoglyceride gelling molecules, which leads to the strong dominance of viscous behavior over elastic behavior. On the contrary, in sample 4, the amount of both modulesG'AndG'' During the increase in temperature, it remained almost unchanged, and therefore the gel-cell transition was not observed in the entire temperature range tested. The reason for this was the absence of a gel network in sample 4 and, as a result, the lack of phase transition due to temperature change. Similarly, the modulus values of sample 4 were constant when heated, while in samples 5 and 8, with the melting of the oily gel network at high temperatures, a sharp increase in tan δ and its approach to 1, indicating a decrease in the strength of the samples compared to It was a true gel (Figure 3). In addition, according to Figure 3, the viscosity of the complex in sample 4 showed a weak dependence on temperature changes, while in samples 6 and 8 at low temperatures, the viscosity of the complex was significantly higher than that of sample 4, and with a further increase in temperature due to melting The formation of a gel network in the oil phase is greatly reduced.

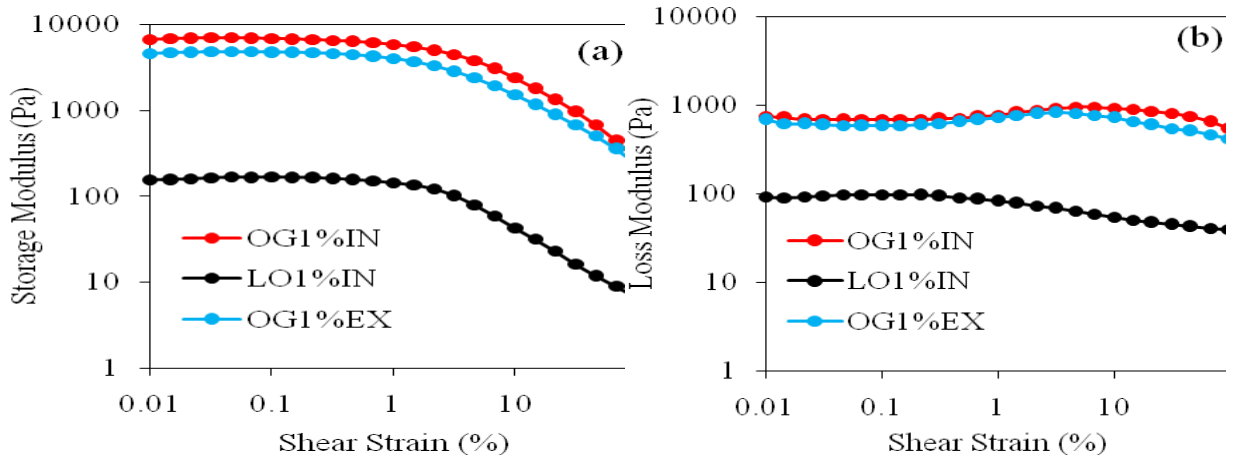

Fig 2 Amplitude sweep test of taste contrast systems. LO1%IN) 1% salt in W_1+ liquid oil, OG1%EX) 1% salt in W_2 + solid oil, OG1%IN) 1% salt in W_1+ solid oil.

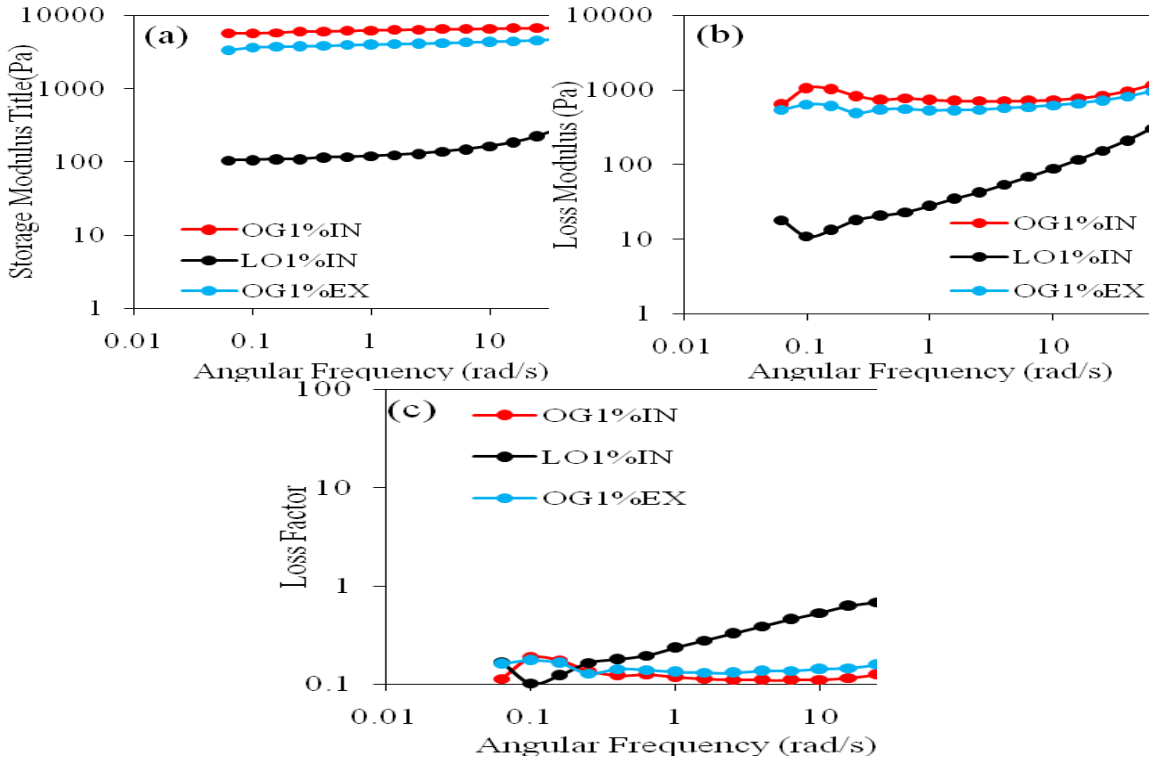

Fig 3 Frequency sweep test of taste contrast systems. LO1%IN) 1% salt in W_1+ liquid oil, OG1%EX) 1% salt in W_2 + solid oil, OG1%IN) 1% salt in W_1+ solid oil.

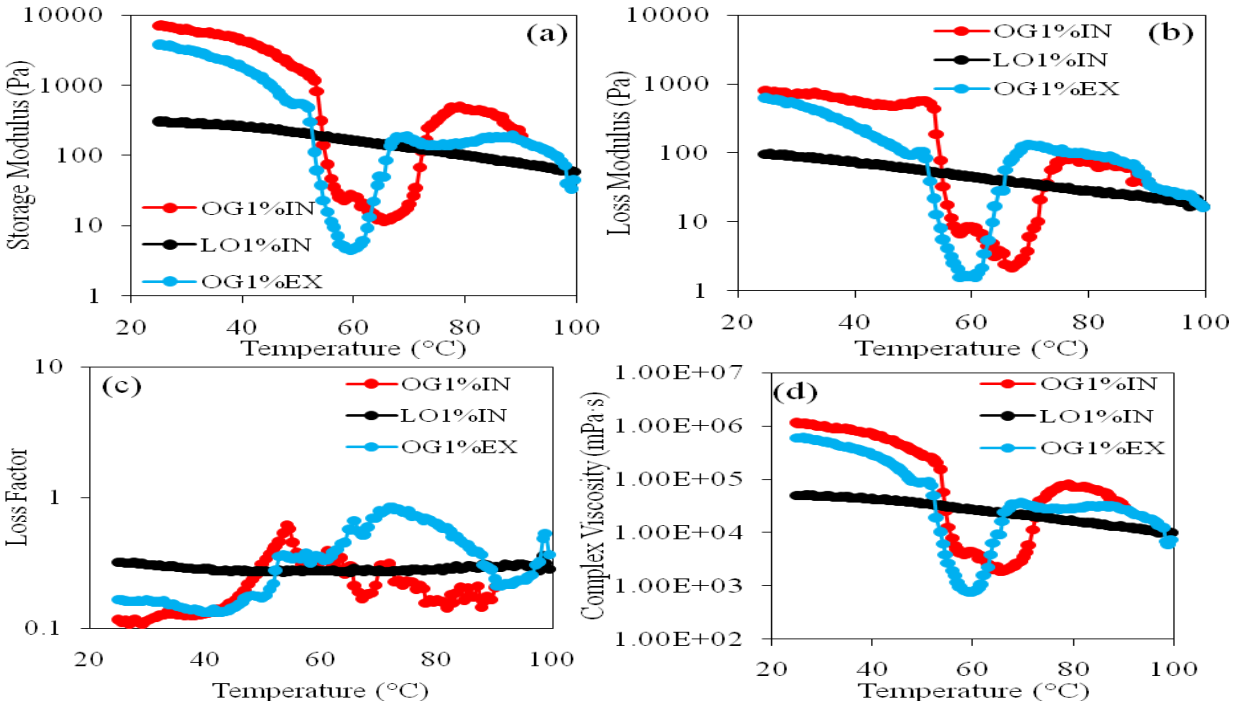

Fig 4 Temperature ramp of taste contrast systems. LO1%IN) 1% salt in W_1+ liquid oil, OG1%EX) 1% salt in W_2 + solid oil, OG1%IN) 1% salt in W_1+ solid oil.

4- General conclusion

In this research, water-in-oil-in-water double emulsions stabilized by an oleogel network in the oil phase were successfully used for encapsulating edible salt and releasing it in a controlled manner, in order to reduce salt consumption and maintain salty taste. For this purpose, in the initial phase of this study, the effect of the physical state of the oily phase, the presence of different percentages of salt in the inner aqueous phase on the stability, encapsulation capacity and physicochemical characteristics of the double emulsion was investigated and compared with the sample containing a certain percentage of salt in the outer aqueous phase. Was performed. In the investigation of stability during the storage period, accelerated stability and heat stability, the sample containing 1% salt in the external phase and the liquid oil phase showed the least stability. On the other hand, the samples containing gel-oil phase maintained their stability well at all salt levels. The samples containing the liquid oily phase and salt embedded in the internal aqueous phase were also relatively stable. The progress of primary and secondary oxidation of emulsion samples did not show any significant difference. In terms of flow behavior, all the samples were quasi-plastic and the viscosity of the emulsion samples designed with an oily gel network was significantly higher than the normal emulsion samples with liquid oily phase. Examining the rheological characteristics of the samples showed that the viscoelastic properties of double emulsions are more influenced by the physical state of the oily phase than the location of the salt. Thus, the values of elastic modulus in the entire frequency range studied for all samples were higher than the viscous modulus, and the stronger viscoelastic properties of the samples containing the oily gel network were confirmed. In studying the effect of temperature on rheological characteristics, for samples containing liquid oily phase, the behavior changes from gel to solid state (in other words, the intersection of drop and storage modulus).The total length of the experiment was not observed, while the destruction of the oleogel network at high temperatures caused the change of the predominance of viscous behavior to elastic behavior in the samples designed with solid oil phase. In general, based on the results, the emulsion sample containing gel network in the oil phase and 0.75% salt in the internal

aqueous phase was selected as the best sample for product production.

5- Appreciation and thanks

This work has been done under the financial support of the National Researchers and Technologists Support Fund (INSF) taken from the post-doctoral project of Mr. Dr. Hadi Hashemi Gharoui under number 4000901.

6- Resources

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مقاله علمی_پژوهشی

تولید و بررسی ویژگی‌های سیستم نوین تمایز طعم شوری توسط امولسیون دوگانه آب در روغن در آب

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اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۱ /۰۴/۲۲

تاریخ پذیرش: ۱۴۰۱/۱۰/۲۹

کلمات کلیدی:

امولسیون دوگانه،

کاهش

نمک،

تکنیک تضاد طعم،

درک شوری،

اولئوژل.

DOI: 10.22034/FSCT.19.132.281

DOR: 20.1001.1.20088787.1401.19.132.21.4

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چکیده

با توجه به ارتباط نزدیک بین مصرف زیاد نمک با افزایش شیوع فشار خون و بیماری قلبی عروقی در دنیا، صنعت غذابرای ایجاد غذاهایی که با انتظارات مصرف کنندگان در مورد کاهش سدیم هماهنگی بهتری داشته باشد در تلاش است. در این مطالعه از راهکار تکنیک تضاد طعم با درون‌پوشانی نمک در فاز آبی داخلی امولسیون دوگانه آب در روغن در آب ($W_1/O/W_2$)، به عنوان یک رویکرد فناورانه جهت کاهش سدیم مورد بررسی قرار گرفت. بدین منظور، در فاز آبی داخلی و فاز روغنی امولسیون‌های دوگانه طراحی شده به ترتیب از غلظت‌های مختلف نمک (۰، ۰/۵، ۰/۷۵ و ۱ درصد) و سینامالدهید (۱ درصد) به عنوان یک ترکیب آنتی‌اکسیدان استفاده شد. جهت بررسی پایداری امولسیون، راندمان درون‌پوشانی و رفتار رهایشی نمک، فاز روغنی در دو حالت مایع و جامد به شکل اولئوژل تولید شد. ویژگی‌های امولسیون‌های تولیدی از نظر پایداری طی دوره نگهداری، پایداری در برابرحرارت و انجماد، رنگ، اکسیداسیون و رئولوژی بررسی شد. بر اساس نتایج بدست آمده، نمونه امولسیونی حاوی شبکه ژلی در فاز روغنی و ۰/۷۵ درصد نمک در فاز آبی داخلی به عنوان بهترین نمونه از نظر پایداری و رفتار رئولوژیکی انتخاب شد.