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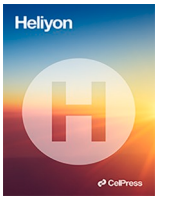

Research article

Iodine values, peroxide values and acid values of Bohai algae oil compared with other oils during the cooking

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ABSTRACT

Objective: Bohai algae oil contains polyunsaturated fatty acids, such as EPA (eicosapentaenoic acid) and DHA (docosahexaenoic acid), which are the very important polyunsaturated fatty acids for the human body. In Traditional Chinese Cooking, all cooking methods cannot do without oils. However, the heat of cooking may always lead to formation of large amounts of decomposition products that affect the sensory, nutritional and functional quality of the oils to be unhealthy and the products being cooked, especially the food or edible oil rich in polyunsaturated fatty acids. Therefore, the objective of this study was to research the effect and change of heating on the quality characteristics of Bohai algae oil comparison with soybean oil and olive oil.
Method: Quality characteristics such as the iodine values (IVs), peroxide values (POVs) and acid values (AVs) of Bohai algae oil, soybean oil and olive oil were measured, cooking conditions as factors of the study.
Result: The POVs percentage changes of Bohai algae oil were larger than the IVs and AVs percentage changes. Bohai algae oil was better heated in a microwave oven at microwave P-20 within 3min, microwave P-60 and P–H1 within 2min, or in induction cooker at 1500w within 1min, or on electric stove (direct heated) within 2min.
Conclusion: Bohai algae oil was suitable used for low-temperature and short-time cooking or for salad. This study has important significance for promoting the commercial value and extensive application of Bohai algae oil in daily cooking. It plays a theoretical significance role in Bohai algae oil's better processing and traditional chinese cooking. It can improve product quality to further expand the food processing research scope of Bohai algae oil and increase the richness, diversity and universality of edible methods of Bohai algae oil.

1. Introduction

Bohai algae oil contains polyunsaturated fatty acids, such as EPA (eicosapentaenoic acid, 20:5 ω-3) and DHA (docosahexaenoic acid, 22:6 ω-3), which are the quietly important polyunsaturated fatty acids for the human body [1–4]. In Traditional Chinese Culture,

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all cooking methods cannot do without oils, especially such as soybean oil, palm oil, corn oil, sunflower oil, olive oil, etc. With the rapid research development of polyunsaturated fatty acid oils and the deeply understanding of their functions, people have added more food oil rich in ω-3 polyunsaturated fatty acids to their daily diet to improve their food sensory quality and nutritional value [4–7]. For example, Coconut olein with palmolein showed better frying stability and the overall sensory quality for frying Poori was the highest to compare with iodine value (IV) in the coconut oil with sesame oil; the coconut olein with sesame oil and coconut olein with palmolein (1:1,v/v ratio) [8].

However the heat of cooking may lead to formation of numerous decomposition products that affect the functional, sensory and nutritional quality of the oils and the products being cooked [9–12]. So during the frying, braising, roasting and cooking process, heating almost damages and reduces the quality of the oil prepared for food. In recent years, many scholars are enthusiastic about studying on the nutrient loss and destruction of food on the different cooking methods. Especially at high temperatures during frying, braising, roasting or cooking oils can automatically alter their quality properties and subsequently make them unhealth. Chemometric analysis had demonstrated that the lowest deterioration of the quality of all refined olive oils during deep-frying at 160 °C and the highest deterioration occurred in the refined sunflower oil during pan-frying at 180 °C [13]. This reveals that different processing or heating conditions could make different effects on different oils. There are some other related studies. Noble blended oil (canola (58.9% monounsat-urated fatty acids): palm oil (45% saturated fatty acids) = 3:7, 4:6, 5:5, 6:4 and 7:3) was prepared and their frying qualities were evaluated. Frying qualities such as fatty acid composition, acid value, peroxide value, viscosity, smoke point, color, antioxidant activity, and sensory evaluation were measured to elucidate the optimum blend ratio of canola and palm oil. The results suggested that the 3:7 (Ca: Pa) blended oil was a good alternative oil for frying potatoes [14]. It also illustrated that the stability of rich ω-3 oil (like Bohai algae oil) is an important problem worth quite studying studying, because it is often unstable during processing. Consequently, it becomes necessary to evaluate the quality of oil.

The iodine values (IVs), peroxide values (POVs), acid values (AVs) are often considered to be major significance indexes for the assessment of quality and stability of oils. IV is important indicative of the degree of unsaturation of a triacylglycerol oil. POV is one of the most typically used quality parameters to monitor lipid oxidation. AV is common measure of the breakdown of the triacylglycrols into free fatty acids, which has an adverse effect [15,16]. Therefore, the objective of this study was to research the effect of heating on the quality characteristics of Bohai algae oil comparison with soybean oil (always for high-temperature cooking) and olive oil (not survive high-temperature cooking) using the IVs, POVs and AVs. These indicators of Bohai algae oil were determined at the different heat treatments, e.g. microwave heating method, induction cooker heating method and electric stove heating method in order to reveal how to use Bohai algae oil better. So it will be good for Bohai algae oil to play its nutritional value and cooking value fully.

2. Materials and methods

2.1. Samples and reagents

Bohai algae oil (content of about 45.27% EPA and 46.19% DHA, from the Food Science and Engineering Laboratory of Jinzhou Medical University) [17]; soybean oil and olive oil (from Jinzhou Shopping Supermarket).

2.2. Effect of the cooking conditions on the quality stability of Bohai algae oil

Different cooking conditions treatment on Bohai algae oil ands soybean oil and olive oil.

Soybean oil, olive oil, and Bohai algae oil (50 g each) were respectively heated in the microwave oven on P–H1 (100% Microwave firepower), P-60 (60% Microwave firepower) and P-20 (20% Microwave firepower) for 1, 2, 3, 4 or 5min. Each oil were respectively heated on the induction cooker at 2100 w, 1800 w, 1500 w for 1 min and heated on the electric stove at 1000 w for 1 and 2 min. Then the IVs, POVs, and AVs of three oils were measured respectively at room temperature.

2.3. Determination of iodine values (IVs)

It was defined as the amount of iodine in grams calculated as the iodine absorbed by 100 g of the sample. The unsaturation of oils or fats was always measured by IVs. The method AOCS Cd 1–25 was used for this determination [18].

2.4. Determination of peroxide values (POVs)

POV, being expressed in milli-equivalents of active oxygen/kg of oil, calculated from the iodine which was released from potassium iodide. The operating of POV was under the conditions indicated in the method proposed by AOCS Cd 8–53 [19]. The value showed the evaluation criterion for incipient rancidity (pre-rancidity, characterized by the formation of unstable peroxides) and indicated the conservation state of fatty matter [19].

2.5. Determination of acid values (AVs)

This index was expressed as the number of milligrams of potassium hydroxide required to neutralize the free acids of 1 g of sample. Free fatty acids of oil were determined in methanol solution, by titration of sodium hydroxide solution using phenolphthalein as indicator. The content of free fatty acid was calculated using the molecular weight of the predominant acid. The method recommended

Table 1
Analysis and multiple comparisons on the IVs, POVs and AVs indexes of Bohai algae oil, olive oil and soybean oil at different heating treatments.

Oil	methods	Power	Time/min	NO.	IVs	±SD	Comparison	POVs	±SD	Comparison	AVs	±SD	Comparison
Bohai algae oil	CON			1	129.227	2.564	A	0.006	0.001	h	1.085	0.130	g
	microwave	P-20	1min	2	103.424	2.564	defg	0.008	0.002	h	1.496	0.171	fg
			2min	3	101.309	4.677	efg	0.013	0.002	fgh	2.132	0.112	def
			3min	4	96.656	2.766	ghi	0.016	0.002	efgh	2.805	0.337	abcd
			5min	5	84.177	3.877	jk	0.021	0.002	defg	3.179	0.282	ab
		P-60	1min	6	114.210	1.938	bc	0.016	0.002	efgh	1.833	0.394	efg
			2min	7	109.346	3.533	bcdef	0.025	0.003	cde	2.394	0.130	bcde
			3min	8	103.635	4.442	defg	0.036	0.008	bc	3.104	0.130	abc
			5min	9	90.311	1.904	hij	0.043	0.005	ab	3.478	0.736	a
		P–H1	1min	10	118.440	2.642	ab	0.032	0.004	bcd	1.683	0.337	efg
			2min	11	117.171	1.597	bc	0.043	0.005	ab	1.907	0.224	efg
			3min	12	109.980	2.766	bcde	0.052	0.006	a	2.319	0.065	bcdef
			5min	13	98.559	2.908	fgh	0.055	0.008	a	2.431	0.343	bcde
	Induction cooker	1500w	1min	14	106.427	6.163	cdefg	0.022	0.001	def	2.244	0.224	cdef
		1800w	1min	15	86.842	2.555	ijk	0.030	0.004	cd	2.805	0.337	abcd
		2100w	1min	16	76.479	1.916	K	0.044	0.004	ab	3.628	0.282	a
	Electric stove	1000w	1min	17	113.787	5.076	bcd	0.009	0.002	gh	2.281	0.065	cdef
			2min	18	112.518	5.815	bcd	0.014	0.001	efgh	3.403	0.171	a
Oil	methods	Power	Time/min	NO.	IVs	±SD	Comparison	POVs	±SD	Comparison	AVs	±SD	Comparison
Olive oil	CON			1	113.576	3.495	A	0.026	0.001	g	1.795	0.194	g
	microwave	P-20	1min	2	74.660	5.396	def	0.030	0.002	fg	2.057	0.467	g
			2min	3	73.814	3.533	def	0.033	0.003	defg	2.394	0.361	fg
			3min	4	62.393	1.904	gh	0.036	0.002	bcdef	2.581	0.194	fg
			5min	5	43.781	2.402	J	0.040	0.001	abcde	2.543	0.282	fg
		P-60	1min	6	93.695	0.969	B	0.034	0.001	cdefg	2.169	0.065	fg
			2min	7	77.621	2.538	cd	0.042	0.005	abcd	2.356	0.405	fg
			3min	8	67.892	2.861	efg	0.043	0.003	abc	2.468	0.297	fg
			5min	9	48.011	0.366	Ij	0.049	0.008	a	2.917	0.514	efg
		P–H1	1min	10	100.463	2.766	B	0.043	0.005	abc	3.291	0.576	efg
			2min	11	86.081	4.225	C	0.042	0.001	abcd	3.441	0.130	efg
			3min	12	68.315	2.040	defg	0.046	0.004	ab	4.114	0.324	ef
			5min	13	52.664	3.130	Ij	0.047	0.001	a	4.750	0.648	de
	Induction cooker	1500w	1min	14	75.294	2.993	de	0.032	0.001	efg	7.330	0.565	c
		1800w	1min	15	66.285	6.376	efg	0.033	0.001	defg	21.617	1.743	b
		2100w	1min	16	56.386	1.909	hi	0.042	0.001	abcd	23.637	1.460	a
	Electric stove	1000w	1min	17	71.910	1.904	defg	0.032	0.001	efg	4.750	0.282	de
			2min	18	65.142	0.733	fgh	0.034	0.001	cdefg	6.470	0.282	cd
Oil	methods	Power	Time/min	NO.	IVs	±SD	Comparison	POVs	±SD	Comparison	AVs	±SD	Comparison
Soybean oil	CON			1	114.422	0.634	a	0.059	0.001	h	1.459	0.000	i
	microwave	P-20	1min	2	93.695	2.228	cdef	0.061	0.001	fgh	2.207	0.234	hi
			2min	3	92.003	1.597	defg	0.063	0.002	defgh	2.394	0.361	ghi
			3min	4	84.389	2.999	fghi	0.065	0.001	defgh	2.543	0.796	fghi
			5min	5	75.294	2.228	i	0.069	0.002	cdefg	2.917	0.194	efgh
		P-60	1min	6	99.617	2.861	bcd	0.060	0.001	gh	2.581	0.224	fghi
			2min	7	95.387	3.533	bcde	0.062	0.001	efgh	2.880	0.553	fg
			3min	8	90.945	2.908	defg	0.069	0.003	cdefgh	3.628	0.648	ef
			5min	9	79.313	1.321	hi	0.072	0.004	cd	4.899	0.576	cd
		P–H1	1min	10	105.116	4.225	ab	0.065	0.001	defgh	2.506	0.343	fghi
			2min	11	104.270	4.161	abc	0.069	0.003	cdefgh	2.842	0.506	efgh
			3min	12	100.463	5.036	bcd	0.070	0.002	cde	3.403	0.065	efg
			5min	13	84.389	4.128	fghi	0.075	0.001	bc	4.862	0.324	cd
	Induction cooker	1500w	1min	14	98.729	2.236	bcd	0.070	0.007	cdef	5.573	0.171	bc
		1800w	1min	15	87.223	5.830	efgh	0.084	0.001	b	6.395	0.194	ab
		2100w	1min	16	81.428	1.679	ghi	0.099	0.008	a	6.882	0.234	a
	Electric stove	1000w	1min	17	91.580	3.533	defg	0.062	0.002	efgh	1.982	0.065	hi
			2min	18	77.832	6.512	hi	0.066	0.002	defgh	3.815	0.194	de

$n = 3$, Different lowercase alphabets in the same column represent significant differences at $p \leq 0.05$.

by AOCS Cd 3d-63 was used [19].

2.6. Calculate the difference and change percentage

Calculate the value of differences (*Dif*) between the treatment group and the control group. The formula is as follows (Formula 1):

$$Dif = V_t - V_c \quad \text{Formula 1}$$

V_t—the IVs (or POVs, or AVs) value of a treatment group;
V_c—the IVs (or POVs, or AVs) value of a control group.
Calculate percentage changes (*PC*, %) of each group using Formula 2.

$$PC\ (\%) = \frac{Dif}{V_{mix}} \times 100\% \quad \text{Formula 2}$$

Dif— the value of differences between the treatment group and the control group;
V_{mix}— the mixture IVs (or POVs, or AVs) value of all groups.
Calculate the accumulated percentage changes (APC) of each group using Formula 3.

$$APC = PC_{IV} + PC_{POV} + PC_{AV} \quad \text{Formula 3}$$

PC_{IV}—the *PC* value of IVs of each group;
PC_{POV}—the *PC* value of POVs of each group;
PC_{AV}—the *PC* value of AVs of each group.
We determined that when the *APC* value was less than 100%, the cooking conditions for oil was better.

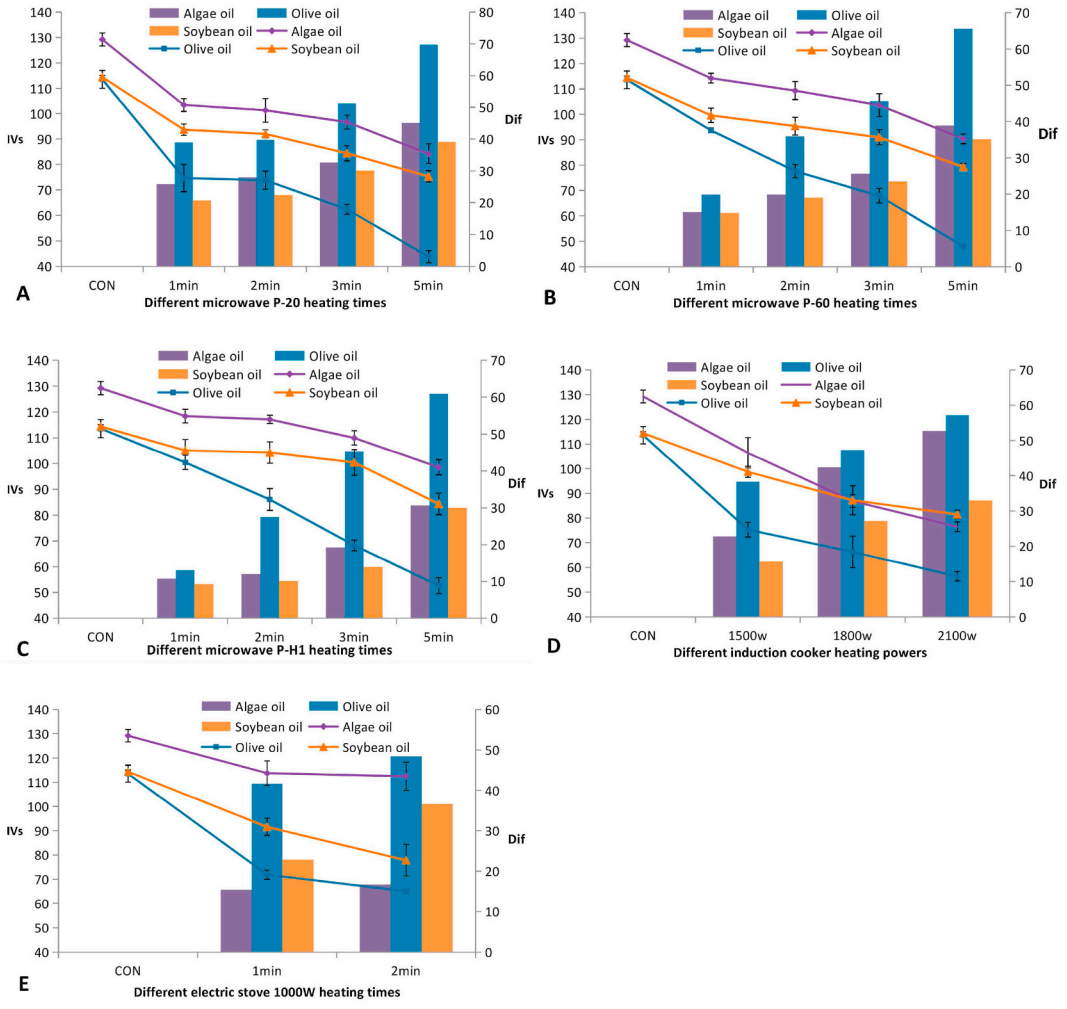

Fig. 1. The IVs of Bohai algae oil, olive oil and soybean oil at different heating treatments.

2.7. Statistical analysis

Data were expressed as mean ± SD. Statistical analysis was performed using a one-way ANOVA and was analyzed further by Tukey HSD test for statistical difference [20]. Different lowercase alphabets in the same column represent significant differences at $p \leq 0.05$. All data analyses were conducted using SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Indexes variations of IVs

The indexes variations of IVs, POVs and AVs about Bohai algae oil, olive oil and soybean oil were shown in Table 1 and Fig. 1 (A-E), changed by the different heating treatments, such as in the microwave oven at different heating powers for different times, or on the induction cooker at different heating powers for different times, or on the electric stove for different times.

$n = 3$, all the figures showed the Iodine values (IVs) of Bohai algae oil, olive oil and soybean oil heated at the different heating times or the different heating powers. Line chart represents IVs value, while bar chart represents Dif value. (A) Microwave at P-20 power. (B) Microwave at P-60 power. (C) Microwave at P–H1 power. (D) Induction cooker. (E) Electric stove at 1000 W power. The results showed that the IVs of the three oils had a tendency to decrease with the heating times and the heating powers. In the control, the IVs of Bohai algae oil was the highest one in the three oils. And the IVs of olive oil reduced most obviously among the three oils. For Bohai algae oil, the IVs in the heating method of electric stove were relatively lower-decrease than the microwave treatment and induction cooker treatment. And the IVs of Bohai algae oil in the heating power of P–H1 were relatively lower-decrease than the P-20 and P-60 treatment. For olive oil, the IVs in electric stove treatment were relatively lower-decrease than the microwave treatment and the induction cooker, same as Bohai algae oil. And the IVs of olive oil in the microwave within 2min were relatively lower-decrease than the other heating treatments. For soybean oil, the IVs of soybean oil in the heating power of P–H1 were relatively lower-decrease than

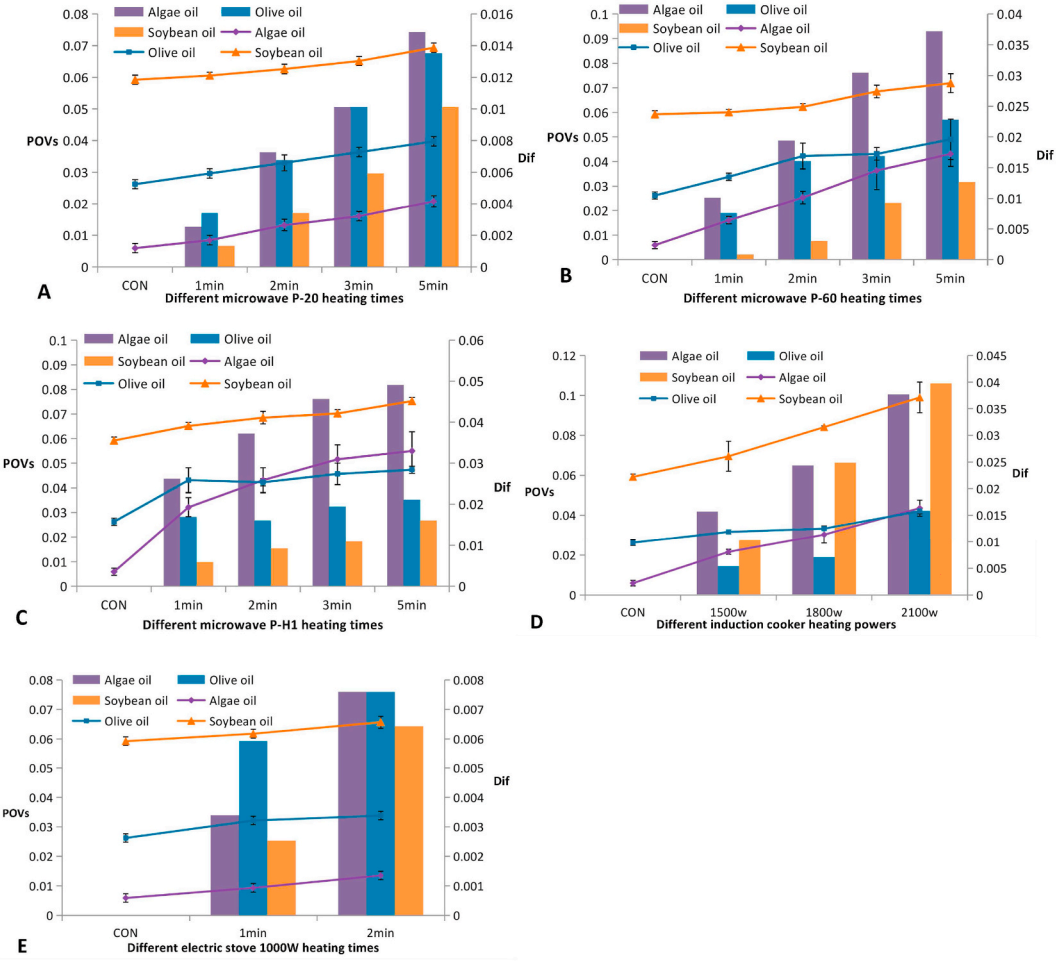

Fig. 2. The POVs indexes of Bohai algae oil, olive oil and soybean oil at different heating treatments.

the other treatments. And the IVs in the others heating treatments had the similar change.

The IVs in chemistry were the mass of iodine in grams that are consumed by 100 g of a chemical substance. Iodine numbers were often used to determine the amount of unsaturation in fatty acids. The unsaturation was in the form of double bonds, which reacted with iodine compounds. The higher the iodine value was, the more carbon double bonds an unsaturated fat had [21]. The cooking process of high temperature such as frying damaged the double bond of unsaturated fatty acids.

In Table 1 and Fig. 1 (A-E), the longer the time of cooking was, the smaller the IVs of three oils were. It meant that the unsaturated double bonds of three oils were less during the cooking. Bohai algae oil retained the most unsaturated double bonds in three oils during the whole process of cooking. This result showed that Bohai algae oil had a higher degree of unsaturation, and it was suitable used for cooking.

Cooking times about no more than 3min were better for three oils. Bohai algae oil was better used at the high-temperature and quick-time cooking. For example, Bohai algae oil was suitable cooked on electric stove at 1000 W, and especially cooked in microwave oven at P–H1. Olive oil and soybean oil were better cooked for the cooking treatments of microwave P–H1 and P-60.

3.2. Indexes variations of POVs

The POVs was defined as the amount of peroxide oxygen per 1 kg of fat or oil. The POVs was often used to determine the concentration of peroxide in an oil or fat. The high-temperature frying process produced a lot of peroxides by oxidation.

$n = 3$, all the figures showed the Peroxide values (POVs) of Bohai algae oil, olive oil and soybean oil heated at the different heating times or the different heating powers. Line chart represents POVs value, while bar chart represents Dif value. (A) Microwave at P-20 power. (B) Microwave at P-60 power. (C) Microwave at P–H1 power. (D) Induction cooker. (E) Electric stove at 1000 W power. The results showed that the POVs of the three oils had a tendency to increase with the heating time and the heating powers. The POVs of the three oils all at the electric stove treatment increased the most slowly, and then was the P-20 treatment. The POVs of Bohai algae oil was the most increased one in the three oils. On the control, the POVs of Bohai algae oil was the lowest one, and the second was olive oil, but soybean oil was the highest one. For Bohai algae oil, the POVs of Bohai algae oil increasing the most obviously was the induction cooker treatment. For olive oil, the increase of POVs was the most obviously. When olive oil was treated by the time up to the 2min in the microwave P–H1, the POVs of olive oil was almost similar to the values of Bohai algae oil at the same time. For soybean oil, the POVs in induction cooker treatment increased with the heating power. The POVs of Bohai algae oil and soybean oil in electric stove treatment increased the most obviously.

In Table 1 and Fig. 2 (A-E), the longer the heating time was, the higher the POVs values of three oils were. It meant that the three oils were easily oxidized during the cooking. The oxidation of soybean oil occurred most easily and the oxidation of Bohai algae oil was the most difficult to occur during the cooking.

Bohai algae oil were better cooked in the microwave oven at P-20 power and cooked on the electric stove at 1000 W, especially in 2∼3min. Olive oil were suitable cooked in the microwave oven at P-20 power, or cooked on induction cooker and electric stove. Most cooking methods were suitable for soybean oil except induction cooker heating method, because the POVs did not change obviously.

3.3. Indexes variations of AVs

In chemistry, AVs was the mass of potassium hydroxide (KOH) in milligrams that was required to neutralize 1 g of chemical substance. The acid number was a measure of the amount of carboxylic acid groups in a chemical compound, such as a fatty acid, or in a mixture of compounds.

$n = 3$, all the figures showed the Acid values (AVs) of Bohai algae oil, olive oil and soybean oil heated at the different heating times or the different heating powers. Line chart represents AVs value, while bar chart represents Dif value. (A) Microwave at P-20 power. (B) Microwave at P-60 power. (C) Microwave at P–H1 power. (D) Induction cooker. (E) Electric stove at 1000 W power. The results showed that the AVs of the three oils had a tendency to increase compared to the control. The AVs of olive oil were higher-increase than the Bohai algae oil and soybean oil in the induction cooker treatment and electric stove treatment. In the control, the AVs of olive oil were the highest one, and then soybean oil was, Bohai algae oil was the lowest one. For Bohai algae oil, the AVs of Bohai algae oil increased fastest among the three oils in microwave treatment. The AVs in the heating method of microwave were relatively lower-increase than the induction cooker and electric stove treatment. And the AVs of Bohai algae oil in the heating power of P–H1 were relatively lower-increase than the P-20 and P-60 treatment. For olive oil, the AVs in the induction cooker treatment had an obvious increase, and the AVs in microwave treatment were relatively lower-increase than the electric stove treatment. When the olive oil treated in short time about 1min, the AVs in lower power had a lower-increase. But when the olive oil treated in long time, the AVs in higher power had a lower-increase. For soybean oil, the AVs in microwave treatment were lower than the induction cooker and electric stove treatment. When the soybean oil treated in short time about 1min, the AVs in lower power had a lower-increase. But when the soybean oil treated in long time, the AVs in higher power had a lower-increase.

Table 1 and Fig. 3 (A-E) showed that the longer the heating time was, the higher the AVs values of three oils were. It meant that the carboxylic acid groups of three oils were increased by oxidation during the cooking. The cooking promoted the decomposition of three oils. The decomposition of olive oil occurred most easily and the oxidation of Bohai algae oil occurred most difficultly during the cooking process. The results showed that the cooking process enhanced the degree of oil deterioration.

Bohai algae oil was best suitable cooked in the microwave oven at P–H1 power. Olive oil was all best cooked in the microwave oven. Soybean oil was best cooked in the microwave oven at P-20 power.

3.4. The value of accumulated percentage changes (APC)

The *APC* values indicated the difference between the treatment group and the control group. It reflected the changes of oxidative stability of Bohai algae oil, olive oil and soybean oil at the different cooking treatments. From Fig. 4 (A-C), Bohai algae oil was better cooked in the microwave oven at P-20 within 3min, at P-60 and P–H1 within 2min, on or cooked on the induction cooker at 1500w within 1min, or cooked on the electric stove within 2min. Olive oil was better cooked in the microwave oven at P-20 within 3min, at P-60 and P–H1 within 2min, or cooked on the induction cooker at 1500w within 1min, or cooked on the electric stove within 1min. For soybean oil, it was better cooked in the microwave oven at P-20, P-60 and P–H1 within 5min, or cooked on the induction cooker at 1500w within 1min, or cooked on the electric stove within 2min. The optimum cooking conditions of Bohai algae oil was similar to olive oil.

4. Discussions and conclusion

Iodine values (IVs), peroxide values (POVs) and acid values (AVs) are often used as the indicators for the oxidative stability of fats and oils [17,22]. They are becoming significance for the assessment of quality and stability of oils [16,17]. Many studies have shown that the oil was to hydrolyze, to oxidize, to decompose and to undergo rancidity by physical and chemical changes after being used long heat time [23]. So there were a large amount ofthe free fatty acids produced from the oils by oxidation during the high-temperature cooking [24]. Peroxide started to induce decomposition, easily leading to convert to a short carbon chain of aldehyde, ketone and aldehyde hydroxyl groups, hydroxyl fatty acids, *trans*-fatty acids, polymerization products, sterol derivatives, and other substances [25–27]. Especially the oil rich in a high unsaturated fatty acids is not suitable for high-temperature and long-time cooking [28–31]. There were several vital factors that could affect the quality of oils during the cooking process, such as composition of the oils used, cooking temperature, cooking time, and the cooking conditions. In this study, we investigated these effect on the Bohai

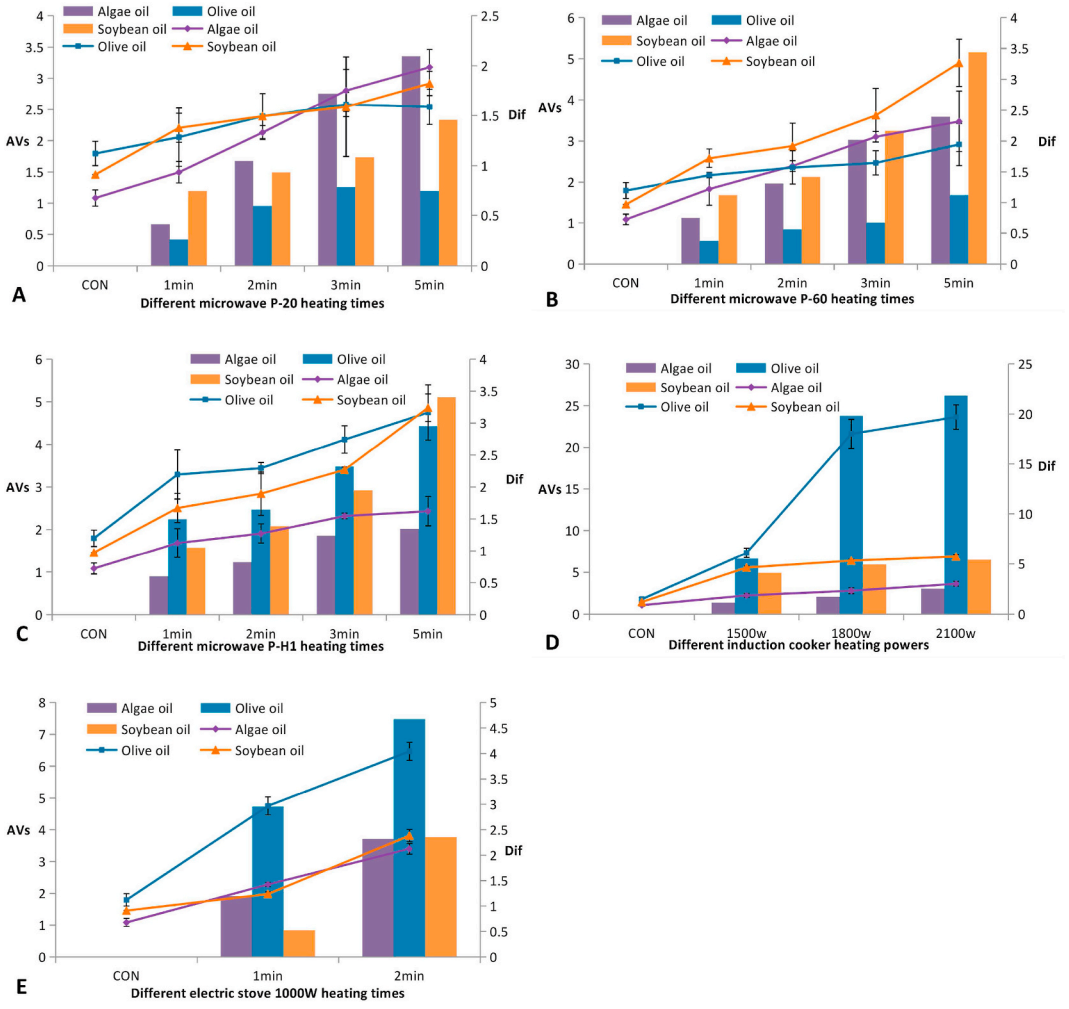

Fig. 3. The AVs indexes of Bohai algae oil, olive oil and soybean oil at different heating treatments.

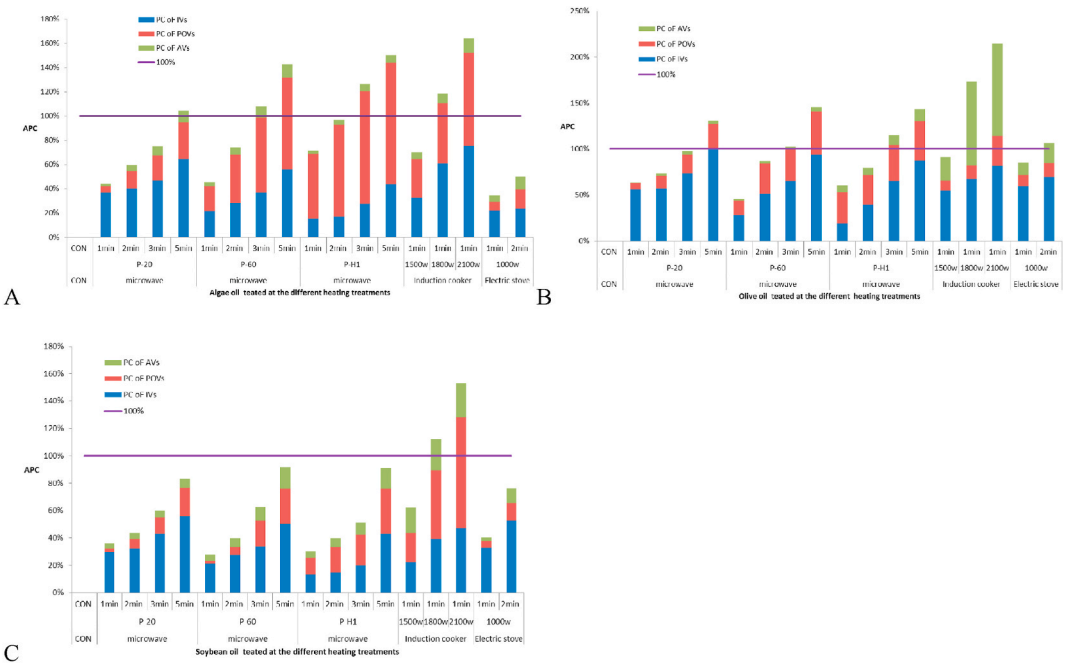

Fig. 4. Comprehensive analysis and comparison on the heating stabilities of Bohai algae oil, olive oil and soybean oil.

algae oil, and compared with soybean oil and olive oil (Fig. 5). Results showed that POVs value presented increasing firstly and then decreasing. It illustrates that the increase of dissociated fatty acid during frying made the oil easier to be rancid [24,28,32,33]. Rancidity generated strong unpleasant odor and changed the sensory characters of oil [34]. Therefore organoleptic qualities and nutrient value was decreased, simultaneously producing some harmful substances.

Bohai algae is a higher degree of unsaturated fatty acids. Bohai algae appeared to desaturation easily during cooking process. But the degree of unsaturation was still higher than soybean oil and olive oil. Bohai algae oil was more easily oxidized during cooking than soybean oil and olive oil. Results showed that Bohai algae oil appeared to rancidity phenomenon easily in the cooking process. It further illuminated that the oils rich in a high amount of beneficial unsaturated fatty acids could bring out qualitative and nutritional damage at high temperature heat and was thus less recommended for frying, similar to some research results [28–31,35]. Therefore, when Bohai algae oil was used as cooking oils, the cooking time should be as short as possible, and within 2min better (Fig. 4) under

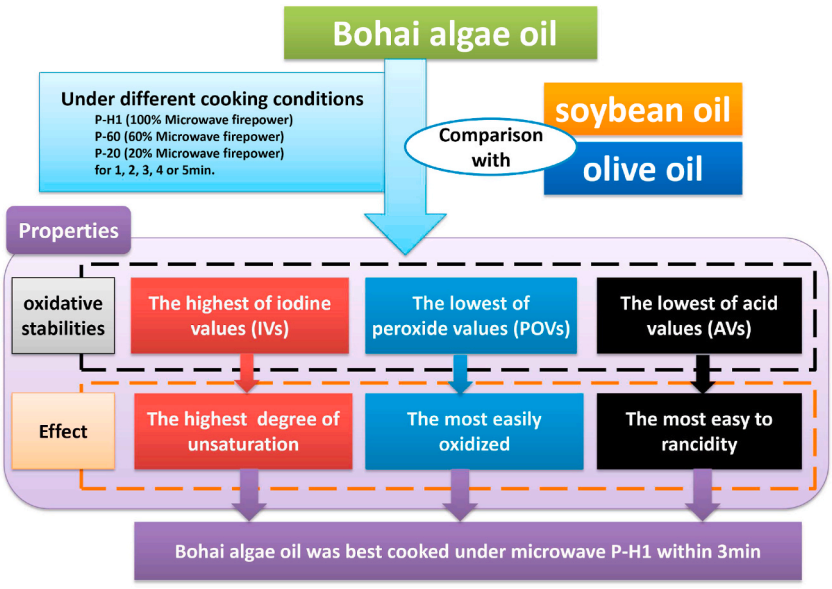

Fig. 5. Main purpose, conclusion and significance of the study.

comprehensive analysis and comparison for the first time. In conclusion, Bohai algae oil was recommended to be cooked in the microwave oven at P-20 within 3min, at P-60 and P–H1 within 2min, or to be cooked in the induction cooker at 1500w within 1min, or to be cooked in the electric stove (direct heating) within 2min. Olive oil was better cooked in the microwave oven at P-20 within 3min, at P-60 and P–H1 within 2min, or to be cooked in the induction cooker at 1500w within 1min, or to be cooked in the electric stove within 1min. Soybean oil was better cooked in the microwave oven at P-20, P-60 and P–H1 within 5min, or to be cooked in the induction cooker at 1500w within 1min, or to be cooked in the electric stove within 2min. Comparing three kinds of oils, soybean oil was most suitable for cook and fry, and the Bohai algae oil and Olive oil were suitable for low-temperature, short-time cook or for salad.

All the figures showed the accumulated percentage changes (*APC*) of Bohai algae oil, olive oil and soybean oil heated at the different heating times or the different heating powers. (A) Bohai algae oil. (B) Olive oil. (C) Soybean oil. The results showed the *APC* of the three oils, which indicated the oxidative stabilities of Bohai algae oil, olive oil and soybean oil. The *PC*s of POVs of Bohai algae oil was larger than the ones of IVs and AVs. We determined that it was better for the cooking conditions in which group the *APC* value was less than 100%. The results showed that the *APC* of Bohai algae oil was less than 100% at microwave P-20 within 3min, microwave P-60 and P–H1 within 2min, induction cooker at 1500w within 1min, and electric stove within 2min. The *APC* of olive oil was less than 100% at microwave P-20 within 3min, microwave P-60 and P–H1 within 2min, induction cooker at 1500w within 1min, and electric stove within 1min. The optimum cooking conditions of Bohai algae oil was similar to Olive oil. The *APC* of soybean oil was less than 100% at microwave P-20, P-60 and P–H1 within 5min, induction cooker at 1500w within 1min, and electric stove within 2min.

Finally, it is concluded that the CPs of POVs of Bohai algae oil was larger than the ones of IVs and AVs. Bohai algae oil was better cooked at microwave P-20 within 3min, microwave P-60 and P–H1 within 2min, induction cooker at 1500w within 1min, and electric stove (direct heating) within 2min. Bohai algae oil was suitable for low temperature, short time cooking or salad. As people's requirements for the quality of life become higher and higher, food health and food nutrition have become the most common words on the lips of people. Therefore, this study has important significance for promoting the commercial value and extensive application of Bohai algae oil in daily cooking. It plays a theoretical significance role in Bohai algae oil's better processing and traditional chinese cooking. We hope this study can improve product quality to further expand the food processing research scope of Bohai algae oil and increase the richness, diversity and universality of edible methods of Bohai algae oil.

Author contributions

LG conceived and designed the experiments. XQ, RS, JL, XW and MS performed the experiments. LG, WZ and MS analyzed and interpreted the data. XQ contributed materials (main rawBohai algae oil). LG and WZ wrote the paper. All authors read and approved the final manuscript.

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Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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