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The effects of AC electric field on wine maturation

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ABSTRACT

A pilot plant scale innovative technique applying AC high voltage electric field to accelerate wine aging of Young Cabernet Sauvignon is reported in this paper. The design principles, equipment configuration and its effect on wine taste and flavour are presented. Results from a sensory evaluation group demonstrated that there were various effects on the wine quality under different conditions, some positive while others negative. An optimum treatment, with electric field 600 V/cm and treatment time 3 min, was identified to accelerate wine aging, which made the harsh and pungent raw wine become harmonious and dainty. HPLC and GC/MS combined with routine chemical analysis methods were used to identify the differences between the treated and untreated samples. It was found that the contents of higher alcohols as well as aldehydes in volatile compounds decreased to a large number, meanwhile, the contents of esters and free amino acids slightly increased while others remained unchanged through all treatments. The results of this study show that the technology of accelerating wine aging by high voltage electric field is a feasible method to shorten wine maturing process times and to improve the quality of a young wine, if favourable process conditions are chosen.

Industrial relevance: The application of physical treatment methods other than heat, such as electric field, magnetic field, ultrasonic wave and microwave, etc., for green processing of foods, is becoming popular. AC electric current is of continuous wave form, thus being seldom used in food processing. However, numerous previous studies about the effect and mechanisms of accelerating wine aging with high voltage AC electric field have been conducted in the Laboratory of South China University of Technology. This manuscript presents the effect of high intensity AC electric field on young wine's physicochemical properties and sensory quality. The results presented in this paper show that it is a promising and novel technology to shorten the young wine's aging period. Recently, a few of the Chinese winery companies have already started to set up the plant scale equipment.

1. Introduction

Grape wine, with a history of over 5000 years, is the most favourite and popular fruit wine all over the world, especially in the western world. Winemaking is not only a scientific technique, but also a kind of artistic skill. In the traditional technology of manufacturing high quality wine, aging in oak barrels is an essential operation in order to obtain the sensorial complexity, colour stability and spontaneous clarification of wine (Ancín, Garde, Torrea, & Jimenez, 2004; Arapitsas, Antonopoulos, Stefanou, & Dourtoglou, 2004; Cerdán & Azpilicueta, 2006; Cerdán, Goñi, & Azpilicueta, 2004; Morales, Benitez, & Troncoso, 2004). Nevertheless, this aging period usually lasts from at least 6 months to over a few years. Thus obviously, for commercial reasons, it is necessary to develop some novel techniques to accelerate the aging course as well as shorten the storage time. Recently, many such kind of alternatives have been applied such as putting new pieces of wood (oak chips or inner staves) into inert containers (Cerdán & Azpilicueta, 2006; Cerdán, Goñi, & Azpilicueta, 2004), adding oak extracts and using wine lees (Moreno & Azpilicueta, 2007).

Actually in the new booming wine manufacture and consumption areas, such as China, there are two different attitudes about using oak barrels or similar materials to age wine. On one hand, most people accept wine as an imported consumable representing high level social status, so they would like to enjoy the wine with its original western style sensory characteristics, which is the special aroma and mouthfeel mainly derived from oak extracted compounds via chemical and biochemical transformations between oak wood and wine. On the other hand, there are also a group of people, including some wine manufactures and suppliers, who consider wine as a kind of new local product and disapprove of using oak in winemaking. Accordingly, young wine or fresh wine with intense fruit aroma, just finished fermentation without oak aging process, is increasingly accepted and demanded nowadays.

It is widely recognized that fresh wine is undrinkable for its harsh taste, pungent smell and some possible harmful side-effects, e.g. it's ease in causing dizziness, headache, thirst, and so on (Watson & Preedy,

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2003). So no matter what kind of method is applied, one thing is certain that the fresh wine should be aged till it is drinkable and marketable. Scientists have put much effort into studying the changes of appearances, flavors, tastes and physical chemical properties of wine during its aging process (Alamo, Bernal, Nozal, & Gómez-Cordovés, 2000; Alcalde-Eon, Escribano-Bailón, Santos-Buelga, & Rivas-Gonzalo, 2006). Some chemical and physical methods have been developed to accelerate the aging course, which involve ultrasonic waves (Chang, 2005; Chang & Chen, 2002; Masuzawa, Ohdaira, & Ide, 2000; Matsuura, Hirotsune, Nunokawa, Satoh, & Honda, 1994) and gamma rays (Chang, 2003). It is reported in these researches that the application of physical field is a promising technique to artificially accelerate the aging course of wine.

In the last 20 years, the application of electric fields in the food and bioengineering area has been explored deeply and developed greatly. These include applying pulsed electric fields for nonthermal sterilization (Toepfl, Heinz, & Knorr, 2007), using electric fields to change protein molecules and improve seed germination for agronomic applications (Cramariuc, Donescu, Popa, & Cramariuc, 2005; Moon & Chung, 2000). In a previous study, several research groups have investigated electric field treatment as an effective method to accelerate young wine aging (Yang, Zeng, Chen, & Xiao, 2003; Zeng, Gao, & Zhang, 2001; Zeng, Zhang, & Geng, 2002). The technique of applying high intense AC electric field on accelerating wine aging has been increasingly intended by Chinese wine factories. Five of them are ready to perform pilot-scale test. However, the application of high frequency AC electric field in wine aging has not been studied worldwide and reported in international journals. The study reported here is aimed to explore the effect of AC electric field on wine aging by applying a set of pilot plant scale equipment. Configurations of the equipment, changes in clarity, color, aroma and taste of treated wines have been investigated.

Numerous researches have pointed out that free amino acids are important functional substances in wine. They are nutrient substances, contribute a lot to the wine's flavor and play a vital role in the wine aging process because they are involved in most of the Nitrogen resources utilizing biochemical reactions (Hernández-Orte, Ibarz, Cacho, & Ferreira, 2005, 2006) Accordingly, the change of amino acids as well as other substances in wine affecting the wine's mouthfeel and quality, such as esters and high alcohols, were also analysed in this paper.

2. Materials and methods

2.1. Pilot plant device

The young wine aged by the accelerated process is subjected to a high voltage AC electric field as described in Fig. 1. Mainly, this set up is composed of three parts: high voltage generator, pump with flow rate controller and treatment chamber. City council power supply (220 V and 50 Hz) is used as the electric source, and flows though a timer and a frequency changer to amplify the frequency to 3000 Hz. A voltage adjustor along with a transformer is used to acquire the high output voltage (up to 30 kV).

The treatment chamber is composed of two parallel plate electrodes made from titanium, and the transfer pipes with its support frame are both insulated materials made from Teflon, and are set up between the electrodes. The distance between the electrodes is fixed at 20 cm. Therefore, the electric field strength in the treatment chamber is determined by the applied voltage. The electric field strength applied to perform the aging experiments is varied from 0 to 900 V/cm. Insulated pipes with inner diameters of 20 mm are connected as "U" shapes and used as the treatment chamber. As the insulated pipes do not have contact with the electrodes directly thus quite low electric current (<10 mA) was generated in the wine. Therefore, little ohmic heat was generated and the mechanism is also very different from ohmic heating. The average power supply was 1 kW, treatment temperature was 25 °C and remain unchanged after being treated, so no cooling process is required.

An electronic pump equipped with a flowmeter is applied to adjust the flow rate and thus control the total flow time of wine through the pipe chamber, which represents the treatment time in the electric field and also the aging time. Electric field strength with three levels of 300, 600 and 900 V/cm and aging time varied among 1, 3 and 8 min, were chosen as variables while electric field frequency (3000 Hz) was fixed in different experiments.

2.2. Wine samples

Young *Cabernet Sauvignon* wine samples were carefully selected from the Suntime Winery Company, Xingjiang grape region, Northwest China, about 3 months after malolactic fermentation. Before the accelerated aging process, the wine underwent clarification applying bentonite and albumin glue followed by sheet and kieselguhr and membrane filtrations. The clear wine was treated by using the equipment shown in Fig. 1 under different electric field strengths and treatment times in the pilot scale workshop. 50 L of wine was used each time. Afterwards, chemical and sensory analyses of the treated wine were carried out with methods as follows.

2.3. Routine analysis

According to the standard analysis methods recommended by O.I.V. (1990) and A.O.A.C. (1995), amino acids were quantified by HPLC (HPX-87H, Aminex columns) (Maicas, Gil, Pardo, & Ferrer, 1999), organic acids were quantified by HPLC (HPX-87H) using the

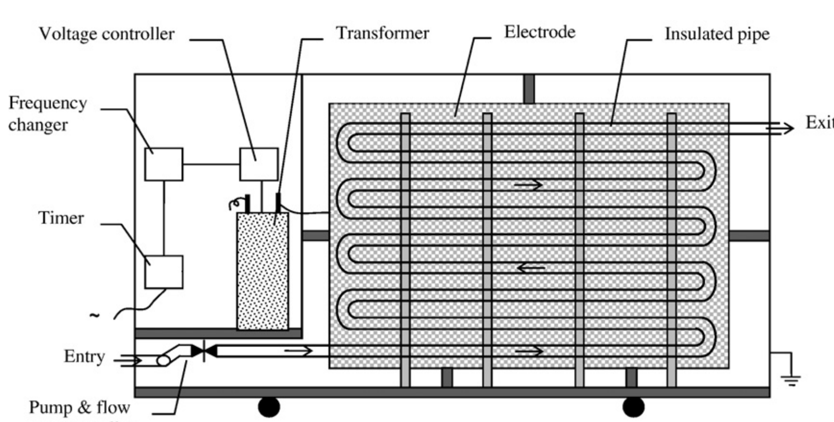

Fig. 1. Configuration of the pilot plant scale electric field set up for wine aging.

Table 1
The variation of compounds contents in different wines subjected to accelerating aging under electric field

Samples	Conditions							Chemical compounds						
	Electric field (V/cm)	Treat Time (min)	Ethanol (%±SE, v/v)	Total sugar (g/l±SE)	Volatile acid (g/l±SE)	Total acidity (g/l±SE)	Dry extract (g/l±SE)	Free amino acids (mg/l±SE)	Higher alcohols (mg/l±SE)	β-phenylethyl alcohol (mg/l±SE)	Ethyl succinate (mg/l±SE)	Diethyl succinate (mg/l±SE)	Ethyl Lactate (mg/l±SE)	Aldehydes (mg/l±SE)
0	0	0	12.96±0.03	2.82±0.15	0.26±0.04	5.52±0.01	26.7±0.2	1229.1±8.7	217.3±5.2	54.8±1.1	134.5±6.7	8.4±0.8	34.4±1.2	2.4±0.2
1-1	300	1	12.92±0.05	2.82±0.11	0.26±0.06	5.50±0.02	26.7±0.3	1232.3±5.7	207.6±7.1	54.5±2.1	135.2±3.2	8.5±1.2	34.2±0.2	2.4±0.5
1-2	300	3	12.88±0.09	2.83±0.05	0.26±0.06	5.48±0.01	26.8±0.3	1245.1±8.	202.6±3.2	55.2±1.9	135.8±5.2	8.5±0.2	35.3±1.3	2.2±0.1
1-2	300	8	12.84±0.05	2.82±0.20	0.26±0.01	5.44±0.03	26.9±0.1	1292.2±25.9	202.3±7.9	54.1±0.8	136.2±1.7	8.8±0.7	34.4±1.2	2.2±0.6
2-1	600	1	12.89±0.04	2.81±0.12	0.26±0.02	5.43±0.02	26.7±0.3	1233.8±11.7	198.3±5.9	54.8±1.3	142.5±2.3	8.4±0.3	35.4±0.5	2.4±0.5
2-2	600	3	12.85±0.03	2.82±0.05	0.26±0.06	5.40±0.03	26.7±0.2	1255.1±8.2	167.1±12.2	55.9±2.1	149.8±4.1	8.8±0.1	34.8±0.9	1.8±0.1
2-3	600	8	12.82±0.05	2.81±0.11	0.26±0.05	5.36±0.02	26.9±0.6	1288.1±36.7	167.3±2.2	57.1±3.2	149.2±6.7	8.8±0.4	35.7±0.7	1.9±0.2
3-1	900	1	12.87±0.06	2.81±0.08	0.26±0.06	5.45±0.02	26.7±0.5	1246.6±6.1	218.3±16.2	52.1±3.1	135.2±4.3	8.5±0.1	34.6±1.3	2.3±0.3
3-2	900	3	12.84±0.04	2.80±0.12	0.26±0.03	5.40±0.01	26.8±0.7	1265.2±18.7	198.7±14.4	55.3±2.2	148.5±7.7	8.7±0.8	33.9±2.2	2.9±0.5
3-3	900	8	12.80±0.02	2.82±0.03	0.26±0.06	5.31±0.02	26.9±0.8	1296.1±35.7	187.3±24.2	55.2±2.5	149.2±8.9	8.8±0.2	35.6±0.4	3.3±0.6

method introduced by Andersson and Hedlund (1983), total sugar were measured by Lane and Eynon titration method (Report of Proceedings, 1978), while acetic acid (referred as volatile acid) were quantified by titration methods (O.I.V., 1990).

2.4. Analysis of volatile compounds

Liquid–liquid extraction and GC–MS were used for the analysis of the volatile compounds in wines. Before entering the chromatography column, the samples were prepared using the following procedures: 350 ml wine was put in a 1 L volume separating funnel, 100 ml analytically pure methylene chloride was added and the separating funnel was shaken intensively for 3–4 min. 3–4 h later when the liquid become clearly stratified, the lower part which was organic phase was released to a 1 L triangular flask. 60 ml methylene chloride was added to the remaining water phase to extract for a second time. Afterwards, the water phase was extracted for another twice time following the same procedures. Subsequently, the organic phases of the three extractions were collected and concentrated to about 5 ml using a rotational-vacuum-evaporator at room temperature. GC–MS analysis was carried out by using a Hewlett-Packard 6890 Series II gas chromatograph coupled directly to a Hewlett-Packard 5972A MSD mass spectrometer. The GC operating conditions were: injection temperature, 250 °C; detector temperature, 280 °C; nitrogen carrier flow rate, 1.2 ml/min; temperature program, 80–240 °C at 6 °C/min and held at 240 °C for 30 min. A split ratio of 80:1 was used. The MS conditions were: transfer temperature 265 °C, the helium carrier flow rate 1.0 ml/min, and the electron multiplier voltage and electron ionization energy were 1353 V and 70 eV, respectively. 2-nonanol was used as the internal standard for quantification.

2.5. Sensory evaluation

Treated and untreated wine samples were evaluated by 12 qualified and experienced wine sensory tasters in a taste room with O.I.V. recommended methods (O.I.V., 1990). Blind tasting and centesimal score system, according appearance (20 scores), aroma (30 scores), taste (40 scores) and typicality (10 scores), were applied to grade the wine quality. From a market value point of view, samples with total scores over 80 were considered as good and acceptable, over 85 were excellent, between 70 and 80 were common, while below 70 were bad and unacceptable. Comments were given to each sample via discussion among all tasters.

3. Statistical analysis

Every analysis was repeated three times and two replications of one specific treatment were performed. Data were reported as mean± standard derivation and statistical significance was declared at $p<0.05$ tested by ANOVA.

4. Results and discussion

Table 1 lists the changes of compound contents in different wine samples subjected to various AC electric field treatments. Corresponding scores and comments are listed in Table 2.

4.1. Routine analysis

Generally, the results in Table 1 showed that most of these main “body substances” of wine, except ethanol and total acid, remained

Table 2
Sensory evaluation of AC electric field treated wines with different treatments contrast to the untreated one

Samples	Electric field (v/cm)	Treat time (min)	Sensory evaluation (Scores)					Total scores (total 100)	Comments
			Clarity (total 10)	Color (total 10)	Aroma (total 30)	Taste (total 40)	Typicality (total 10)		
0	0	0	8.0	7.5	20.0	28.0	7.0	70.5	Clear, ruby red color, pungent alcohol scent with intense fruit aroma, full-bodied while astringent, unbalanced harsh taste
1-1	300	1	8.0	7.5	20.5	30.0	7.0	73.0	Astringency decreased slightly, others unchanged
1-2	300	3	8.0	7.5	22.0	32.5	7.0	77.0	Smell and taste trended to soft and harmony, others unchanged
1-3	300	8	8.0	7.5	22.5	33.5	7.5	79.0	Aged wine scent appeared, the balance of taste improved
2-1	600	1	8.0	7.5	22.0	33.5	7.5	78.5	Slight aged wine aroma, complexity improved and balanced
2-2	600	3	8.0	8.0	25.5	35.0	8.5	85.0	Pleasing fruit and aged wine fragrance, full-bodied while well-balanced and harmonious taste with perfect typicality
2-3	600	8	8.0	8.0	23.5	34.5	8.0	82.0	New unpleasant scent and coarse taste emerged
3-1	900	1	8.0	7.5	22.0	34.0	7.5	79.0	Fresh fruit smell faded while aged wine scent emerged. Softer mouthfeel while unbalanced taste acquired.
3-2	900	3	8.0	8.0	19.5	31.5	6.5	73.5	Faint new unpleasant scent blended with aged wine aroma, complexity improved while unbalanced
3-3	900	8	8.0	8.0	17.5	28.5	6.5	68.5	Burning, disharmonious mouthfeel with unpleasant scent, unacceptable change

unchanged under various electric field conditions. It demonstrated that there was little effect of electric field treatment on the wine's body chemical components. However, for ethanol and total acid content, small changes, though indistinctively, can be observed among the samples. Obviously, they decreased with the increase of electric field within the same treatment time, as well as the increase of treatment time within the same electric field. Under the most severe condition (900 V/cm, 8 min), the ethanol content decreased from 12.96% (untreated) to 12.80% (treated), while the total acid content decreased from 5.52 g/l (untreated) to 5.31 g/l (treated) at the same time. This implies that some chemical reactions of consuming these two chemicals, such as esterification, may have occurred under the electric field treatment. It was demonstrated in Table 1 that the main acids in the wine were organic acids, such as tartaric acid, lactic acid, succinic acid, etc., which was 5.4 g/l altogether. This content was much higher than that of acetic acid (0.26 g/l). Accordingly, the content of ethyl succinate, diethyl succinate and ethyl lactate were increased after treatment due to the esterification while the content of ethyl succinate and diethyl succinate were increased after PEF treatment due to esterification.

4.2. HPLC analysis

The data in Table 1, shows that the content of total free amino acids significantly increased in wines after exposure to electric field. Compared to the untreated sample (1229.1 mg/l), under the medium strength treatment (600 V/cm, 3 min) and most severe treatment (900 V/cm, 8 min), the total amino acids content in wine were 1255.1 mg/l and 1296.1 mg/l, which increased by 2.1% and 5.4% respectively. The detail changes of each single free amino acid were listed in Table 3. It can be concluded that the total amino acids content increased with the increase of electric field and the increase of treatment time while the content of single free amino acid behaved differently. The possible mechanism of new free amino acids formation may due to protein degradation, especially the breakage of S–S bonds. This can be identified by the change of cysteine (Cys) which is the main amino acids contain S element in molecular structure. After AC electric treatments, the amount of free cysteine in wine dramatically increased from 3.2 mg/l (untreated) to 11.3 mg/l (300 V/cm, 3 min), 18.4 mg/l (600 V/cm, 3 min) and 22.3 mg/l (900 V/cm, 8 min). This result fits the conclusion drawn elsewhere (Chen, Zeng, Dong, & Yang, 2004).

4.3. GC/MS analysis

4.3.1. Higher alcohols

Normally, *n*-propanol, *iso*-butanol (2-methyl-1-butanol), *iso*- and active amyl alcohol (3-methyl-1-butanol and 2-methyl-1-butanol), are called as higher alcohols or fusel oils altogether. They are the most common alcohols next to ethanol in wine. According to the research of Rankine (1967), *iso*-amyl alcohol has an objectionable odour and a very burning taste, *iso*-butanol is less offensive and *n*-propanol has a spirituous odour but a slightly burning taste. The concentrations of these higher alcohols in treated wine samples and untreated wine sample were listed in Table 1.

It can be observed in Table 1 that the content of higher alcohols dramatically decreased after AC electric field treatments. Among all samples, the wine with lowest higher alcohols content was the one treated under 600 V/cm for 3 min (167.1 mg/l), which decreased by 23.1% in contrast to the untreated one (217.3 mg/l). However, when the wine was being treated for the same time (3 min) under 900 V/cm, the content of high alcohols was 198.7 mg/l. It is demonstrated that there likely exists an optimum treatment condition (electric field and time) to acquire the lowest content of higher alcohol. This optimal preference in this research was 600 V/cm electric field strength and 3 min treatment time. The content of higher alcohols was negatively correlated to the mouthfeel for its harsh taste, therefore, the decrease of higher alcohols' content meant the improvement of wine taste and quality. As for the reaction mechanism, one possible explanation to this phenomenon is that esterification occurred, though this explanation is not reliable as there is insufficient evidence to support this. Thus, deeper research on this point should be carried out later. As regards β-phenylethyl alcohol, an important aroma compound in wine with pleasing rose scent, no significant differences were found under all treatments.

4.3.2. Esters

As can be seen from Table 1, the amount of top three esters (ethyl succinate, diethyl succinate and ethyl lactate), which are main aroma resources in wine generated from esterification between alcohols and acids, were significantly affected by electric field treatments. The content of ethyl succinate, the dominant ester in all samples, increased from 134.5 mg/l (untreated one) to around 149 mg/l after being treated by the electric field with 600 V/cm or 900 V/cm for 3 min to 8 min. Similarly, under the same treatment conditions, the amount of diethyl succinate increased from 8.4 mg/l to about 8.8 mg/l. Meanwhile, the amount of ethyl lactate exhibited no clear trends under all treatments. The sum contents of these three esters were 185.7 mg/l, 193.4 mg/l and 193.6 mg/l for the untreated one, treated sample under 600 V/cm for 3 min, and treated sample under the most severe condition (900 V/cm for 8 min), respectively, which demonstrated that the sum of three domain esters in wine increased by 4.1%–4.3% after being treated by AC electric field. According to the scent characteristic of esters, the increase of esters amount means an enhancement of fruit flavor in wine.

4.3.3. Aldehydes

The date in Table 1 demonstrated that aldehydes, which are harmful and off-flavor substances with lower boiling points, presented a quite different behavior among all compounds analysed. When the lowest strength electric field (300 V/cm) was applied, the content of aldehydes decreased from 2.4 mg/l to 2.2 mg/l after being treated for 3 min, while afterwards no change occurred with longer treatment. Under the electric field with 600 V/cm, the content of aldehydes dramatically decreased to 1.8 mg/l after being treated for 3 min. However, when the treatment time prolonged to 8 min, it increased a little from 1.8 mg/l to 1.9 mg/l instead of further decreasing. It demonstrated that some new aldehydes had been generated. This conclusion was clearly confirmed by the results acquired under the highest electric field level (900 V/cm), when the treatment time was prolonged from 1 min to 8 min, the content of aldehydes decreased at the first 1 min from 2.4 mg/l to 2.3 mg/l, then reversely increased to 2.9 mg/l (3 min) and even as high as 3.3 mg/l (9 min). This interesting phenomenon, quite different from the reports by applying other kinds of physical methods (Chang, 2003; Chang & Chen, 2002), showed that as for reducing the content of aldehydes, it was neither the more intense the electric field nor

Table 3
The change of free amino acids in wine after AC electric field treatments (mg/L)

Amino Acids	Untreated	300V/m, 3min	600V/m,3min	900V/m, 8min
Asp	10.2	10.4	9.4	10.5
Glu	22.0	18.4	20.9	22.9
Ser	10.6	10.1	11.5	12.0
Gly	11.0	10.5	11.9	12.4
His	22.3	22.1	24.9	25.7
Arg	22.6	17.1	21.3	26.6
Cys	**3.2**	**11.3**	**18.4**	**22.3**
Ala	-	-	-	-
Pro	994.0	1006.1	1007.1	1009.1
Tyr	57.4	54.7	57.9	63.8
Val	5.8	5.4	6.6	10.5
Met	-	-	-	-
Thr	25.9	29.3	28.9	29.6
Ile	1.7	5.0	5.8	5.1
Leu	34.6	33.8	33.7	34.5
Phe	2.0	4.9	3.1	7.0
Lys	5.9	5.0	6.8	-
Total	1229.1	1244.1	1270.1	1292.0

the longer the treatment time the better. The optimum treatment to acquire the lowest aldehydes in this study, as the optimum condition for the lowest content of higher alcohols, was 600 V/cm and 3 min.

4.3.4. Sensory evaluation

According to the evaluations of 12 disciplined tasters, the total scores and comments of each wine sample were listed in Table 2. Based on the criteria mentioned in the former part of this paper, it can be seen from Table 2 that among all treated samples one sample with excellent value of sensory scores, one sample with goof value of sensory scores (acceptable) were obtained while all others remained in common level. The sample with highest value, acquired under 600 V/cm for 3 min, scored 85 and was appraised as "pleasing fruit aroma blended with intense aged wine fragrance, full-bodied while well-balanced and harmonious taste with perfect typicality", which was greatly improved as compared to the untreated one with 70.5 scores and "pungent alcohol scent with intense fruit aroma, full-bodied while astringent, unbalanced harsh taste". However, when this sample was treated under the same electric field (600 V/cm) for 5 min more (total 8 min), its sensory evaluation decreased to scores of 82 due to new unpleasant scents that emerged and the balance of the taste was destroyed, though it was still considered as a sample with quite good value and commercially acceptable sample.

It was also demonstrated that the treatments by AC electric field under various conditions affected the wine sensory differently. Some effects were positive while others were negative. For most of the treated samples except sample 3-2 and sample 3-3, their sensory value was improved after being treated. Meanwhile, under the most severe electric field condition (treated sample 3–3 900 V/cm for 8 min), many negative effects about the wine quality appeared during the treatment, which involved its aroma becoming strange and unpleasant, its body became more unbalanced and disharmonious. The worst effect was that the taste became burning and undrinkable. For those samples under the same electric field with shorter treatment time (sample 3-1 and 3-2), these changes also had occurred, though to a lesser extent.

The results obtained from sensory evaluation were highly agreement with the results of higher alcohols and aldehydes analysis: there likely exists an optimum treatment condition for obtaining the wine with the highest sensory quality, i.e., electric field 600 V/cm and treatment time 3 min. More intense electric field or longer treatment time would cause some negative effects and worse sensory value.

4.3.5. Comparison with other aging techniques

As being treated by application gamma irradiation (Chang, 2003), all AC electric field treated wine samples demonstrate a decrease of higher acohols content. As for the change of aldehyde quantity, it significantly increases under all gamma irradiation treatments. Meanwhile under the AC electric field treatments, it decreases a little under the gentle conditions, such as 600 V/cm for 3 min, and increases dramatically when the condition changes to severer, such as 900 V/cm for 8 min. This phenomenon means that the application of external physical field (electric field or gamma irradiation) affects the molecular structure and chemical reactions among the substances in wine.

5. Conclusion

Generally, the application of the AC electric field seems to be a promising novel process to artificially accelerate the aging process of fresh wine when suitable conditions are applied. In this study, the sensory quality of the treated wine under AC electric field 600 V/cm for 3 min was found to be much better than the untreated one and other treated samples. This treated sample was highly appraised as with high sensory value by the sensory evaluation group and considered as commercially marketable. However it also can be concluded that if the operating conditions are not chosen properly, an adverse effect is also possible to acquire. As far as all the analysed compounds are concerned, higher alcohols and aldehydes are the most sensitive compounds, then followed by esters and free amino acids, while others almost remained unchanged when they exposed to external AC electric field. Taking all the aspects into consideration, it seems that the changes of chemical compounds are not sufficient to explain the sensory variations so far, especially when the aspects of mouthfeel balance and new unpleasant scents are concerned. Finally, the mechanisms concerning hydrogen bonding among ethanol and water molecules should be taken into account as suggested in some literature (Nose, Myojin, Hojo, Ueda, & Okuda, 2005; Peeters and Leroy, 1994).

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References

Alamo, M. D., Bernal, J. L., Nozal, M. J. D., & Gómez-Cordovés, C. (2000). Red wine aging in oak barrels: Evolution of the monosaccharides content. *Food Chemistry*, *71*, 189–193.

Alcalde-Eon, C., Escribano-Bailón, M. T., Santos-Buelga, C., & Rivas-Gonzalo, J. C. (2006). Changes in the detailed pigment composition of red wine during maturity and ageing: A comprehensive study. *Analytica Chimica Acta*, *563*, 238–254.

Ancín, C., Garde, T., Torrea, D., & Jimenez, N. (2004). Extraction of volatile compounds in model wine from different oak woods: Effect of SO2. *Food Research International*, *37*, 375–383.

Andersson, R., & Hedlund, B. (1983). HPLC analysis of organic acids in lactic acid fermented vegetables. *European Food Research and Technology*, *176*(6), 440–443.

A.O.A.C. (1995). *Official methods of analysis.* Wahsingtong D.C. USA: Association of Official Analytical Chemists.

Arapitsas, P., Antonopoulos, A., Stefanou, E., & Dourtoglou, V. G. (2004). Artificial aging of wines using oak chips. *Food Chemistry*, *86*, 563–570.

Cerdán, T. G., & Azpilicueta, C. A. (2006). Effect of oak barrel type on the volatile composition of wine: Storage time optimization. *LWT*, *39*, 199–205.

Cerdán, T. G., Goñi, D. T., & Azpilicueta, C. A. (2004). Accumulation of volatile compounds during ageing of two red wines with different composition. *Journal of Food Engineering*, *65*, 349–356.

Chang, A. C. (2003). The effects of gamma irradiation on rice wine maturation. *Food Chemistry*, *83*, 323–327.

Chang, A. C. (2005). Study of ultrasonic wave treatments for accelerating the aging process in a rice alcoholic beverage. *Food Chemistry*, *92*, 337–342.

Chang, A. C., & Chen, F. C. (2002). The application of 20 kHz ultrasonic waves to accelerate the aging of different wines. *Food Chemistry*, *79*, 501–506.

Chen, Y., Zeng, X. A., Dong, X. P., & Yang, H. F. (2004). Effects of aging-acceleration by electric field on free amino acid of claret. *Liquor-Making Science & Technology*, *4*, 80–81.

Cramariuc, R., Donescu, V., Popa, M., & Cramariuc, B. (2005). The biological effect of the electrical field treatment on the potato seed: agronomic evaluation. *Journal of Electrostatics*, *63*, 837–846.

Hernández-Orte, P., Ibarz, M. J., Cacho, J., & Ferreira, V. (2005). Effect of the addition of ammonium and amino acids to musts of Airen variety on aromatic composition and sensory properties of the obtained wine. *Food Chemistry*, *89*, 163–174.

Hernández-Orte, P., Ibarz, M. J., Cacho, J., & Ferreira, V. (2006). Addition of amino acids to grape juice of the Merlot variety: Effect on amino acid uptake and aroma generation during alcoholic fermentation. *Food Chemistry*, *98*, 300–310.

Maicas, S., Gil, J. V., Pardo, I., & Ferrer, S. (1999). Improvement of volatile composition of wines by controlled addition of malolactic bacteria. *Food Research International*, *32*, 491–496.

Masuzawa, N., Ohdaira, E., & Ide, M. (2000). Effects of ultrasonic irradiation on phenolic compounds in wine. *Japan Journal of Applied Physics*, *39*, 2978–2979.

Matsuura, K., Hirotsune, M., Nunokawa, Y., Satoh, M., & Honda, K. (1994). Acceleration of cell growth and ester formation by ultrasonic wave irradiation. *Journal of Fermentation and Bioengineering*, *77*(1), 36–40.

Moon, J. D., & Chung, H. S. (2000). Acceleration of germination of tomato seed by applying AC electric and magnetic fields. *Journal of Electrostatics*, *48*, 103–114.

Morales, M. L., Benitez, B., & Troncoso, A. M. (2004). Accelerated aging of wine vinegars with oak chips: Evaluation of wood flavour compounds. *Food Chemistry (Analytical, Nutritional and Clinical Methods)*, *88*, 305–315.

Moreno, N. J., & Azpilicueta, C. A. (2007). Binding of oak volatile compounds by wine lees during simulation of wine ageing. *LWT-Food Science and Technology*, *40*(4), 619–624.

Nose, A., Myojin, M., Hojo, M., Ueda, T., & Okuda, T. (2005). Porton nuclear magnetic resonance and Raman spectroscopic studies of Japanese sake, an alcoholic beverage. *Journal of Bioscience and Bioengineering*, *99*(5), 493–501.

O.I.V. (1990). *Recueil des methodes internationales d'analyse des vins et des mouts.* Office International de la Vigne et du Vin.

Peeters, D., & Leroy, G. (1994). Small clusters between water and alcohols. *Journal of Molecular Structure (Theochem)*, *314*, 39–47.

Rankine, B. C. (1967). Formation of higher alcohols by wine yeasts, and relationship to taste thresholds. *J. Sci. Fd Agric*, *18*, 583–589.

Report of Proceedings (1978). *Seventeenth Session International Commission for Uniform-Methods of Sugar Analysis, ICUMSA, Peterborough, England.*

Toepfl, S., Heinz, V., & Knorr, D. (2007). High intensity pulsed electric fields applied for food preservation. *Chemical Engineering and Processing*, *46*, 537–546.

Watson, R. R., & Preedy, V. R. (2003). *Nutrition and alcohol: Linking nutrient interactions and dietary intake.* Washington, D. C.: CRC Press.

Yang, H. F., Zeng, X. A., Chen, Y., & Xiao, L. M. (2003). Study on the accelerating fresh wine aging by high intensity electromagnetic field. *Liquor Making*, *30*, 40–42.

Zeng, X. A., Gao, D. W., & Zhang, B. S. (2001). Study on aging rice wine with high voltage electric field. *Food and Fermentation Industries*, *27*(6), 50–53.

Zeng, X. A., Zhang, B. S., & Geng, Y. H. (2002). FTIR analysis of the alcohol solution treated by high voltage electric field. *Spectroscopy and Spectral Analysis*, *22*(1), 29–32.