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The effects of different accelerating techniques on maize wine maturation

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Abstract

The effects of different accelerating techniques on maize wine maturation were investigated. Maize wine was fermented by *Saccharomyces sake* and matured using 20 kHz or 1.6 MHz ultrasonic waves, γ-irradiation or 1 year's conventional maturation. Alcohol content, titratable acidity, presence of γ-irradiation residues, gas chromatographic measurements and organoleptic sensory evaluation were studied. The relationships of the instrumental evaluation to organoleptic sensory evaluation of each of the processes were also studied, as well as the time of maturation. Results showed that the accelerating techniques of ultrasonic wave treatments, at both power levels, and γ-irradiation treatments, matured maize wine more quickly than standard maturation, but not all wine was as high in quality as that matured conventionally. γ-Irradiation appeared to be a better method for improving maize wine defects, while producing a good tasting maize wine, than ultrasonic wave treatments.

Keywords: Accelerating techniques; Maize wine; Maturation

1. Introduction

Wine is mainly produced by alcoholic fermentation in which yeasts and other microorganisms convert glucose or single sugar monomers to alcohol. Wine making material can be diverse as long as it supplies sugar; wine fermentation length influences wine quality and wine can also be aged in many ways. Each brand of wine has its own special and unique production method, developed over time to produce a unique type of wine. Fermenting produces alcohol, flavour and taste, originating from wine-making materials and their derivatives, but it is maturation that gives wine the properties that make it pleasurable and valuable. There have been studies of many aspects of wine, such as functional groups of phenolics of wines (Castellari, Matricardi, Arfelli, & Amati, 2000; Ho, Hogg, & Silva, 1999; Pena-Neira, Hernandez, Garcia-Vallejo, Estrella, & Suarez, 2000), wine constituent analyses (Masuda, Yamanota, & Asakura, 1985; Sato, Suzuki, Okuda, & Yokotsuka, 1997), aroma compound effects studies (Cocito, Gaetano, & Delfini, 1995; Maduagwu, 1982; Matsuura, Hirotsune, Nunokawa, Satoh, & Honda, 1994; Nouadje et al., 1997; Simpson & Miller, 1983) and the effects of microorganisms, ethanol cost and/or wine making materials (Ayed et al., 1999; Bachir, 1999; Core, 2002; Riponi & Carnacini, 1997) but very little work was found (and/or was not written in English) comparing the effects of different accelerating techniques of 20 kHz and 1.6 MHz ultrasonic wave treatments, γ-irradiation with 1-year conventionally matured maize wine (market maturing way) on grain wine material.

Maize is a very important, yet economical, grain product. America is the largest consuming/producing country in the world with more than 40% of global production according to USDA's National Agricultural Statistics Service (Core, 2002). America's Bourbon whisky, which uses maize as a major ingredient, is one of the three major world markets as famous as French Cognac and Scotch whisky (Murray, 1998).

Literature review indicates that ultrasound power provides high temperature and high pressure for the modification of chemical reactions (Saterlay & Compton,

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2000; Suslick, 1989). Our previous studies (Chang & Chen, 2002), on the application of 20 kHz ultrasonic waves to accelerate the aging of different wines, showed that 20 kHz ultrasonic wave treatment aged rice wine much more quickly than 1-year conventionally standard aging, with similar quality, but did not age maize wine with comparable quality. The 20 kHz ultrasonic wave treatment has potential as a good alternative method of aging wine made from some materials, such as rice, but not all. Cocito et al. (1995) studied the effects of rapid extraction of aroma compounds in must and wine by means of ultrasound by using 48 kHz ultrasonic waves to extract the aromatic compounds of must and wine. Matsuura et al. (1994) investigated the possible application of 43 kHz ultrasonic waves to the fermentation control of wine, beer and sake made from a saccharified rice solution, particularly for reducing dissolved carbon dioxide levels.

With regard to the literature survey of γ-irradiation, the general conclusion is that the advantages are mass energy transmission with no, or relatively low heat, which is good for limiting many chemical reactions; no industrial catalyst is needed and there is a saving of time. The major concern is that there is still debate about this technology (Eyck & Deseran, 2001). Literature on the application of γ-irradiation, specifically on wines, that is internationally available, is scarce. Hua, Chen, Yu, and Huang (1989) studied the acceleration of yellow wine mellowness by using cobalt-60 γ-rays. They conducted the study using 10–60 krad γ-ray irradiation. Their results showed that ester compounds were increased after γ-irradiation. When comparing yellow wine irradiated with 10–60 krad γ-rays to wine conventionally aged for half a year, 1 year and $1\frac{1}{2}$ years, they found that the irradiated yellow wine quality reached that of the $1\frac{1}{2}$ year conventionally aged yellow wine. The flavour, taste and mellowness of the irradiated yellow wine improved. They also did a hygiene and safety experiment and showed that the irradiated wine had no influence on human health and that the hygienic quota satisfied their national standard. In their study, they performed toxicity tests on rats. Rats fed 10 g/kg by weight were found to be healthy. Also, an experiment on micro-nuclear cells showed negative results in rats. However, a lot of important things were not described or not described in detail, especially in the section on materials and methods, plus the language was not English, nor was the publication available to the general public. Caldwell and Spayd (1989) researched the effects of γ-irradiation on chemical and sensory evaluation of Cabernet Sauvignon wine. In their study they found that γ-irradiation of red wine did increase the chemical colour age of the Cabernet Sauvignon wines. Sensory evaluations found no perceivable difference in the doses (600, 1200 and 2400 Gy) that they used. Also, the γ-irradiation did not decrease the astringency of the wines studied. They also reported that the use of higher dose rates to rapidly age Cabernet Sauvignon wines did not appear to be feasible. This paper did not have any information on the use of lower dose rates to rapidly age Cabernet Sauvignon wines.

Our paper reports the effects of using 20 kHz ultrasonic waves, 1.6 MHz ultrasonic waves, different doses (200, 400, 600 and 800 Gy) of γ-irradiation and a 1-year standard maturation process to mature maize wine. It studies the effects of alcohol content, titratable acidity, presence of γ-irradiation residues, gas chromatographic measurements and organoleptic sensory evaluation. The relationships of the instrumental evaluations to organoleptic sensory evaluations were also studied, as well as the time of maturation.

2. Materials and methods

The maize wine was made with a 1:1 ratio (by volume) of whole dry, mechanically crushed, grain maize (yellow dent, market bought, 14% water, dry basis) and water. Four litres of a 1:1 maize/water mixture was cooked at 125 °C for 1 h and then cooled with a fan to room temperature (25 °C). When this cooked maize reached room temperature, 4 litres of water (pre-boiled and cooled to room temperature) were blended into the maize to semi-liquefy the cooked maize. This process was repeated five times for 20 kHz ultrasound, five times for 1.6 MHz ultrasound, five times for different doses of γ-irradiation artificial maturing treatments and five times for 1-year conventionally matured maize wine. *Aspergillus awamori* (CCRC 30891) was then inoculated into the semi-liquefied maize in order to produce amyloglucosidase, glucoamylase, α-amylase and β-glucuronidase (FIRDI, 2000) to hydrolyse the maize starch polymers into smaller starch oligo-carbohydrate polymers and sugar monomers; the hydrolysis processes also further liquefied the semi-liquefied maize for more complete fermentation processing. About 1 h later, with the temperature constant around 25 °C, *Saccharomyces sake* (CCRC 20262) was inoculated into the liquefied maize and kept at 25 °C for fermentation. The fermentation took place in 30-litre closed fired clay containers, which were vibrated 2–3 times a day to facilitate fermentation. After the fermentation was completed (14–16 days, depending on the designed desired alcohol content, 16–20% alcohol in our experiment), the maize wine was collected using the 80 °C distillation method and was ready for the 20 kHz, 1.6 MHz ultrasonic wave treatments and 200, 400, 600, 800 Gy γ-irradiation of the accelerated maturation processes (artificial maturation processes) or for the 1-year standard maturation process (conventional maturation process), with temperature constant around 25 °C for the entire maturing year. Analyses were done immediately after wines were collected using the 80 °C distillation method and ready for the artificial maturation processes or for the 1-year conventional maturing process. These analyses of the maize wine, prior to all studied maturing process, were conducted as a check index to check on all the start qualities of the four different maturing processes (20 kHz ultrasound, 1.6 MHz ultrasound, γ-irradiation and 1-year conventional maturation time) to assure as close a quality level to as possible before commencement. If the start qualities were not at the levels of a normal range of maize wines (set at ±5% in our experiment design), further efforts were needed, such as to re-do the fermentation process or check on all conditions or any problems which may have occurred.

The 1-year conventionally matured wine was matured by placing it into three 30-litre fired clay containers for 1 year prior to conducting the accelerated maturation processes. A maturation time of 1 year is the standard for conventionally maturing Asian market grain wines, and analysis at that maturation time was done. About 1 year later, the wine to be matured by accelerated methods was matured by the two ultrasonic processes and one γ-irradiation process. Analyses were done immediately after the accelerated maturation processes were completed. The accelerated matured maize wine was matured about 1 year after the maize wine conventionally matured by 1 year so that analyses of the conventionally matured wine and accelerated matured wine could take place concurrently. Moreover, the maize wine-making techniques, for both conventional standard matured and accelerated matured, were as close as possible to exactly the same for all tested samples in our study in order to produce similar maize wine sample qualities and to minimize the bias as much as possible. In any case, if biases were greater than ±5% of our experimental design, further efforts would be needed, such as checking for possible problems.

Both power levels (20 kHz and 1.6 MHz ultrasonic wave set-ups) were designed and self-made by two experts in mechanical engineering, one from our school and one from the Institute of Nuclear Energy Research of Taiwan. The 20 kHz and 1.6 MHz ultrasonic wave generators were used to apply ultrasound energy to the maize wine. Both ultrasonic wave generators had piezoelectric chips, which generated electrons. When the electrons accumulated, they vibrated in terms of ultrasonic waves. The ultrasonic nozzle orifice for 20 kHz was 10 mm while that for 1.6 MHz was 4 mm. We chose 10 and 4 mm orifice nozzles because these nozzle's amplitude energies were found, by trial, to fit our experimental needs in terms of atomizing the bulk wine liquids into a spray of smoke-like mist droplets to fulfill the ultrasonic process. The maize wine volume for one ultrasonic treatment run was 2 litres and was replicated three times. All the ultrasonic maturing treatments were set at 25 °C and were in a closed chamber to prevent evaporation loss of the maize wine and assure the best collection of the misted maize wine. The maize wine was repeatedly treated, up to 16 times for the 20 kHz process and up to four times by the 1.6 MHz ultrasonic wave process. The entire processing time of each was considered as the time of maturation and was used for comparison with conventional maturation. Samples of the treated maize wine were collected after 0 (untreated, immediately after distillation), 4, 8, 12 and 16 treatments for 20 kHz power levels of ultrasonic waves and were collected after 0 (untreated, immediately after distillation), 1, 2, 3 and 4 treatments for 1.6 MHz levels of ultrasonic waves. The maize wine for the γ-irradiation maturation process was randomly grouped into five lots and bottled in 600-ml glass screw-cap wine bottles. For each lot, triplicate maize wine samples were irradiated at doses of 0, 200, 400, 600 and 800 Gy of cobalt irradiation at a dose rate of 20 Gy/min, using a cobalt-60 irradiator (plane source, 45.15 cm long, 1.11 cm diameter, Nordion, Canada) at the Institute of Nuclear Energy Research of Taiwan, ROC. The γ-irradiated maize wine was stored at room temperature (around 25 °C) for 7 days prior to analysis.

Each of all the studied samples was analysed for titratable acidity, presence of γ-irradiation residues (for γ-irradiation treatment samples only), alcohol content, gas chromatographic measurements and organoleptic sensory evaluation. The relationships of the contents of titratable acidity, alcohols, esters, volatile acids and aldehydes to organoleptic sensory evaluations, along with the time of maturation were also studied. All analyses were done in triplicate and the results given as averages of triplicate data.

The titratable acidity was calculated as acetic acid due to its domination in the maize wine, and the titratable acidity value was measured by the A.O.A.C. (1995) method and converted by calculating the volume of 1 N NaOH used. This gave an indication of acidity and the level of sour flavour of the wine; it also was an index of possible contamination during the entire study and an index of rancidity. If the acidity level was out of a normal range of maize wine (set as ±5% wine in our experiment), further tests were needed such as re-doing the fermentation process or checking on any problems which may have occurred, such as bad temperature control, contamination and/or rancidity.

The presence of γ-irradiation residues was tested for the samples of γ-irradiation treatments using the Geiger–Muller counter (Mini, EP15FL, UK) to check whether any possible contamination remained in the irradiated maize wine samples.

Alcohol was measured in all of the samples with a KYOTO, DA-310, electric specific gravity meter. Alcohol was then calculated from the gravity measurements by the A.O.A.C. method (1995). The alcohol content check gave an indication of possible alcohol changes in the processes.

Flavour compounds were analysed by a WHIRLPOOL 5790 gas chromatograph with a glass column that was 1.8 m long, 2 mm thick, packed with 6.6% carbowax and 20 M/80–120 mesh carbopack B Aw, using a flame ion detector (FID). The carrier gas was nitrogen with 20 ml/min flow rate. The injection temperature was 150 °C and the FID temperature was 200 °C. The gas chromatograph temperature gradient started at 60 °C and stayed at the level for 1 min. It then increased at 5 °C/min and reached 160 °C in 20 min where it stayed for 2 min. Each sample injection amount was 2 μl. Standards for the gas chromatograph were prepared as follows: 0.5 ml of 5.14% acetaldehyde, 2 ml of 5.0% ethyl acetate, 2 ml of 5.0% ethyl lactate, 0.4 ml of 5% 2-phenyl-ethanol, 0.2 ml of 5% 1-propanol, 0.4 ml of 5% 2-methyl-1-propanol, 1 ml of 2% 2-methyl-butanol and 1 ml of 2% 3-methyl-butanol were mixed with 40% ethanol to reach 100 ml in total.

Sensory evaluations were made by 12 qualified and experienced wine sensory tasters using the Krammer preference priority organoleptic method which has a statistical significance of $\alpha = 5\%$ and had been applied widely for the purpose of wine tasting (Huang, 1984; Sato, 1988; Wang, 1980; Zhai, 2000). Each of the 12 tasters tasted the maize wine before any treatments and after each of the 4 (for 1.6 MHz), each of the 16 (for 20 kHz) ultrasonic wave treatments, and each of 200, 400, 600 and 800 Gy γ-irradiation treatments. The tasters ranked the treated maize wine against the maize wine conventionally matured for 1 year. They gave the treated maize wine a ranking of 1 (best) to higher scores (worse). Generally, a quality conventionally matured maize wine would be ranked 1 on this scale, and the higher the score the worse the quality. The results were then calculated and analysed by the summation of the preference priorities of each taster and ranked from best to worst flavour.

Time of maturation for the wines matured by the accelerated processes was counted as the time needed to complete the entire ultrasonic wave maturation processes and entire γ-irradiation aging process versus the 1-year conventional maturation process.

3. Results and discussion

The alcohol content in the maize wine matured with 20 kHz ultrasonic waves decreased slightly as the number of treatments increased (Table 1). The alcohol content of the maize wine (50%) samples treated 16 times by 20 kHz ultrasonic waves was about the same as the alcohol content (50%) of samples matured by the standard 1-year process. The alcohol content in the maize wine matured with 1.6 MHz ultrasonic waves decreased as treatment time increased (Table 2). The alcohol content of the maize wine (48%) samples treated four times by 1.6 MHz ultrasonic waves was lower than the alcohol content (50%) of the samples treated 16 times by 20 kHz ultrasonic waves and the alcohol content (50%) of samples matured by the standard 1-year process. The alcohol content of the maize wine (52%) samples treated by γ-irradiation was the same as the alcohol content (52%) of samples non-irradiated (Table 3). Results showed that the maturation techniques of 1.6 MHz ultrasonic process lost alcohol the most, 20 kHz and 1-year standard processes lost the second, while the γ-irradiation process resulted in no lost alcohol content (Tables 1–3).

Titratable acidity of all tested samples of 20 kHz and 1.6 MHz ultrasonic wave treatments, γ-irradiation and 1-year conventionally matured maize wine remained the same as the treatments increased and doses increased (Tables 1–3). This showed that the acids, which also contribute to the flavours of wine, were not positively or

Table 1
The titratable acidity value, alcohol content, acetaldehyde content, ethyl acetate content, 2-phenyl ethanol content and selected alcohol content of 20 kHz ultrasonic wave-treated maize wine with different treatments vs. 1-year conventionally matured maize wine, fresh maize wine (untreated) and control maize wine (prior to 1-year conventionally matured)

No. of ultrasonic treatments (20 kHz)	Titratable acidity (g/100 ml)	Alcohol (v/v%)	Acetaldehyde (mg/litre)	Ethyl-acetate (mg/litre)	2-Phenyl-ethanol (mg/litre)	Selected alcohols			
						1-Propanol (mg/litre)	2-Methyl-1-propanol (mg/litre)	2-Methyl-butanol (mg/litre)	3-Methyl-butanol (mg/litre)
0 (untreated)	0.0058	52	48	114	48	198	513	154	505
4	0.0058	52	47	97	37	200	513	154	505
8	0.0058	51	46	83	30	202	515	156	509
12	0.0058	51	45	68	24	205	528	158	510
16	0.0058	50	42	61	18	207	535	160	512
Control maize wine	0.0058	52	48	114	48	198	513	154	505
1 year aged maize wine	0.0058	50	40	121	70	200	513	154	505

Table 2
The titratable acidity value, alcohol content, acetaldehyde content, ethyl acetate content, 2-phenyl ethanol content and selected alcohol content of 1.6 MHz ultrasonic wave-treated maize wine with different treatments vs. 1-year conventionally matured maize wine, fresh maize wine (untreated) and control maize wine (prior to 1-year conventionally matured)

No. of ultrasonic treatments (1.6 MHz)	Titratable acidity (g/100 ml)	Alcohol (v/v%)	Acetaldehyde (mg/litre)	Ethyl-acetate (mg/litre)	2-Phenyl-ethanol (mg/litre)	Selected alcohols			
						1-Propanol (mg/litre)	2-Methyl-1-propanol (mg/litre)	2-Methyl-butanol (mg/litre)	3-Methyl-butanol (mg/litre)
0 (untreated)	0.0058	52	48	114	48	198	513	154	505
1	0.0058	51	54	110	36	210	519	158	508
2	0.0058	50	62	108	22	215	524	163	514
3	0.0058	49	70	101	18	219	529	169	519
4	0.0058	48	79	94	12	223	533	174	523
Control maize wine	0.0058	52	48	114	48	198	513	154	505
1 year aged maize wine	0.0058	50	40	121	70	200	513	154	505

Table 3
The titratable acidity value, alcohol content, acetaldehyde content, ethyl acetate content, 2-phenyl ethanol content and selected alcohol content of γ-irradiation-treated maize wine with different doses vs. 1-year conventionally matured maize wine, fresh maize wine (non-irradiated) and control maize wine (prior to 1-year conventionally matured)

γ-Irradiation dosage	Titratable acidity (g/100 ml)	Alcohol (v/v%)	Acetaldehyde (mg/litre)	Ethyl-acetate (mg/litre)	2-Phenyl-ethanol (mg/litre)	Polyols			
						1-Propanol (mg/litre)	2-Methyl-1-propanol (mg/litre)	2-Methyl-butanol (mg/litre)	3-Methyl-butanol (mg/litre)
0 Gy (non-irradiated)	0.0058	52	48	114	48	198	513	154	505
200 Gy	0.0058	52	58	114	48	175	402	149	476
400 Gy	0.0058	52	67	114	48	162	341	147	463
600 Gy	0.0058	52	75	114	48	141	307	143	439
800 Gy	0.0058	52	80	114	48	108	239	141	426
Control maize wine	0.0058	52	48	114	48	198	513	154	505
1 year aged maize wine	0.0058	50	40	121	70	200	513	154	505

negatively affected by any of our studied artificial maturation techniques on the standard 1-year maturation process. It also showed that the studied fermentation processes were correct; there were no rancidity on contamination problems throughout the entire study.

The results of the contamination check for the presence of γ-irradiation residues, in all γ-irradiation-treated samples, showed no contamination of any sample over the entire study. The results matched those found in the literature review and demonstrated that γ irradiation could be a safe and applicable technique (Caldwell & Spayd, 1989; Eyck & Deseran, 2001).

The results of gas chromatography measurements were as follows: acetaldehyde, an off-flavour, which has the lowest boiling point of the flavour compounds of wines, increased in the 1.6 MHz ultrasonic wave-treated maize wine and also increased in the γ-irradiation-treated wine as treatment time increased and irradiated doses increased (Tables 2 and 3). The amount of acetaldehyde decreased in 20 kHz ultrasonic wave-treated wine as treatment time increased and also decreased as in 1-year conventionally matured maize wine (Table 1). The R^2 of the linear regression equation of the increasing of 1.6 MHz was 0.995 with a slope of 7.8 and intersection of 39.2 mg/litre. The R^2 of the linear regression equation of the increasing of γ-irradiation was 0.986 with a slope of 8.1 and intersection of 41.3 mg/litre. The R^2 of the linear regression equation of the decreasing of 20 kHz was 0.924 with a slope of −1.4 and intersection of 49.8 mg/litre. All the R^2 values indicated a linear relationship of acetaldehyde content and different accelerating treatments. Ethyl acetate, which has an apple and/or fruity flavour, and 2-phenyl ethanol, which has a rosy and/or good smell of flowers, are the fragrant compounds in wine. The amounts of ethyl acetate and 2-phenyl ethanol were both decreased by 20 kHz and 1.6 MHz ultrasonic waves as treatment time increased (Tables 1 and 2). The amounts of ethyl acetate and 2-phenyl ethanol did not change with γ-irradiation treatment at any dose (Table 3). The amount of ethyl acetate increased slightly in 1 year conventionally matured maize wine (from 114 to 121 mg/litre) but 2-phenyl ethanol increased dramatically, from 48 to 70 mg/litre (Tables 1–3). The R^2 of the linear regression equation of the decreasing of ethyl acetate by 1.6 MHz treatment was 0.956 with a slope of −4.9 and intersection of 120.1 mg/litre. The R^2 of the linear regression equation of the decreasing of 2-phenyl ethanol by 1.6 MHz treatments was 0.949 with a slope of −9 and intersection of

54.2 mg/litre. The R^2 of the linear regression equation of the decreasing of ethyl acetate by 20 kHz treatments was 0.983 with a slope of −13.5 and intersection of 125.1 mg/litre. The R^2 of the linear regression equation of the decreasing of 2-phenyl ethanol by 20 kHz treatments was 0.981 with a slope of −7.3 and intersection of 53.3 mg/litre. All the R^2 values indicate a linear relationship of fragrant contents and different accelerating treatments.

Alcohols, such as 1-propanol, 2-methyl-1-propanol, 2-methyl-butanol and 3-methyl-butanol, often have rice-oil off-flavours and cause a greasy after-taste in the mouth. The amounts of alcohols were increased by both 20 kHz and 1.6 MHz ultrasonic waves as treatment time increased but did not change in 1-year conventionally matured maize wine. The amounts of alcohols decreased dramatically as γ-irradiation treatment doses increased. The R^2 values of the linear regression equations of the increasing of alcohols by 20 kHz treatment were 0.994, 0.852, 0.941 and 0.930 with slopes of 2.3, 5.9, 1.6 and 1.9, and intersections of 196, 503, 152 and 503 mg/litre for 1-propanol, 2-methyl-1-propanol, 2-methyl-butanol and 3-methyl-butanol, respectively. The R^2 values of the linear regression equations of the increasing of polyols by 1.6 MHz treatment were 0.931, 0.995, 0.996 and 0.992 with slopes of 5.9, 5, 5.1 and 4.7, and intersections of 195, 509, 148 and 500 mg/litre for 1-propanol, 2-methyl-1-propanol, 2-methyl-butanol and 3-methyl-butanol, respectively. All the R^2 values indicate a linear relationship between alcohol contents and different accelerating treatments.

Smell, taste and tactile properties of wines are key deciding factors for human preference. Not all properties, especially dealing with human preference, are detectable instrumentally. Human organoleptic sensory evaluation plays an important role in determining which wines humans find pleasurable. Results showed that the ultrasonic wave treatments, both at the low power level of 20 kHz and high power level of 1.6 MHz, appeared not to be suitable methods for achieving the maturation quality requirement (Tables 4 and 5). The quality of maize wine that was γ-irradiated improved as irradiated doses increased (Table 6). The maize wine that had 800 Gy γ-irradiated treatment was rated nearly as good as the 1-year conventionally matured maize wine but less comparable in smoothness or mouth feel. The γ-irradiation maturation technique on maize wine appeared to be a potential method for achieving the maturation quality requirement as an alternative method for maturing maize wine. It improved some maize wine defects and produced higher taste quality in the wine. Time and space were saved as well. However, the fear of irradiation needs to be addressed.

Table 4
Sensory evaluation of 20 kHz ultrasonic wave-treated maize wine with different treatments vs. 1-year conventionally matured maize wine and fresh maize wine (untreated)

Taster	Rank					
	Untreated	4 times	8 times	12 times	16 times	1-year conventionally matured maize wine
Rank summation	21	33	48	60	72	12
Preference	2	3	4	5	6	1

Table 5
Sensory evaluation of 1.6 MHz ultrasonic wave-treated maize wine with different treatments vs. 1-year conventionally matured maize wine and fresh maize wine (untreated)

Taster	Rank					
	Untreated	1 time	2 times	3 times	4 times	1-year conventionally matured maize wine
Rank summation	20	31	48	60	72	12
Preference	2	3	4	5	6	1

Table 6
Sensory evaluation of γ-irradiation-treated maize wine with different doses vs. 1-year conventionally matured maize wine and fresh maize wine (non-irradiated)

Taster	Rank					
	Non-irradiated	200 Gy	400 Gy	600 Gy	800 Gy	1-year conventionally matured maize wine
Rank summation	72	50	39	26	16	12
Preference	6	5	4	3	2	1

In organoleptic evaluation, comments are complicated. Preference priority may vary with a taster's age, curiosity, memories, affections and smells, flavour, impressions and colour of samples (Murray, 1998). Therefore, the relationship of the contents found instrumentally to organoleptic quality are subjective and the results were as follows: the titratable acidities of all tested samples matured by 20 kHz or 1.6 MHz ultrasonic waves, γ-irradiated with different doses and 1-year conventionally matured were not positively or negatively correlated as the amounts remained the same in all processes. Alcohol decreased most in 1.6 MHz ultrasonic wave treatments as treatment times increased and decreased slightly in 20 kHz ultrasonic wave treatments as treatment times increased. This, combined with the increase in off flavours, both in the greasy aftertaste of alcohols and acetaldehyde, as treatment times increased and the decrease of fruity rosy fragrant flavours, as treatments increased, made the ultrasonic wave maturation techniques appear not to be feasible. As in γ-irradiation, although the titratable acidity and the alcohol showed no effects throughout the entire study, the fruity, fragrant ethyl acetate increased slightly and especially the rosy/flower fragrance of 2-phenyl ethanol, which increased dramatically as γ-irradiation doses increased and made the γ-irradiated maize wine smell better as doses increased. As well as the greasy mouth feel, off-flavours of alcohols and acetaldehyde also decreased, and the tasters preference increased as γ-irradiation doses increased and the quality of 800 Gy-irradiated maize wine was nearly as good as 1-year conventionally matured maize wine except in the smoothness and mouth feel. In general, γ-irradiation appeared to be a feasible potential method among the three studied artificial maturing methods for improving some defects and producing higher taste quality in maize wine.

The three studied artificial maturing techniques of maturing maize wine are all much faster than the 1-year conventionally matured maize wine maturing process. Maize wine could potentially be matured to near the quality taste of market maize wine within 1 h by using γ irradiation. Maize wine did not mature properly with the ultrasonic wave treatments process at both power levels of ultrasound (20 kHz and 1.6 MHz), but it only took about 1 week for 20 kHz and 1 day for 1.6 MHz versus 1 year of conventional maturation. However, education on the elimination of radioactive residue fear is necessary.

4. Conclusion

In general, γ-irradiation appeared to be a feasible potential method among the three studied artificial maturing methods for improving some defects and producing higher taste quality in maize wine. Ultrasonic wave treatments of both power levels of ultrasound (20 kHz and 1.6 MHz) did not yield promising results. However, toxicity effects and appropriate dose checks may need study and the public should be educated to lessen the fear of γ-irradiation.

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