Mgr inż. Jan PIECKO [1]
Dr hab. inż. Dariusz PIOTROWSKI [2]
Dr hab. inż. Monika MIESZCZAKOWSKA-FRĄC, prof. IO [1]
[1] The National Institute of Horticultural Research
Fruit and Vegetable Storage and Processing Department, Skierniewice, Poland
Instytut Ogrodnictwa – Państwowy Instytut Badawczy
Zakład Przechowalnictwa i Przetwórstwa Owoców i Warzyw, Skierniewice, Polska
[2] The National Institute of Horticultural Research
Horticultural Products Processing Center, Skierniewice, Poland
Instytut Ogrodnictwa – Państwowy Instytut Badawczy
Centrum Przetwórstwa Produktów Ogrodniczych, CPPO, Skierniewice, Polska

EFFECT OF ULTRASOUND ON THE CONTENT OF BIOACTIVE COMPOUNDS AND SELECTED QUALITY PARAMETERS IN BERRY JUICES®

Wpływ ultradźwięków na zawartość związków bioaktywnych oraz wybrane parametry jakościowe w sokach z owoców jagodowych®

This work was supported by the NOR / POLNOR / QualityBerry 0014/2019-00 /2019 co-financed by The National Centre for Research and Development and Norway grants. Project implemented as part of the Norwegian Financial Mechanism for 2014–2021. „We act together for a green, competitive and favoring social integration Europe".

Key words: berries, ultrasound, juice, proposed treatment, processing options.

Current nutritional trends make consumers interested in foods and beverages that provide bioactive compounds with health-promoting effects. Such compounds include anthocyanins, which are polyphenolic compounds with anti-inflammatory, anti-carcinogenic and antioxidant properties. Berry juices, used in beverage production, are a good source of polyphenols, especially anthocyanins. This paper discusses the effect of ultrasound on the quality in terms of chemical composition, sensory and microbiological quality of berry juices. The results of current research directions of ultrasounds application are discussed; both at the stage of pulp processing prior to juice pressing and the direct juice treatment. The research indicates that the use of ultrasound can be an alternative to other methods of treating the raw material before pressing, and due to the non-thermal nature of the process does not cause serious degradation of anthocyanins. What's more, the use of this technology will make it possible to lower the temperature of the pasteurization process, which make possible to preserving the sensory qualities of the juices.

Słowa kluczowe: owoce jagodowe, ultradźwięki, sok, proponowana obróbka, opcje przetwarzania.

Aktualne trendy żywieniowe powodują, że konsumenci są zainteresowani żywnością oraz napojami, które dostarczają związków bioaktywnych o działaniu prozdrowotnym. Do takich związków należą antocyjany, które są związkami polifenolowymi o właściwościach przeciwzapalnych, przeciwkancerogennych i przeciwutleniających. Soki z owoców jagodowych, wykorzystywane w produkcji napojów, są dobrym źródłem polifenoli, a w szczególności antocyjanów. W niniejszym artykule omówiono wpływ ultradźwięków na jakość soków z owoców jagodowych pod względem składu chemicznego, jakości sensorycznej i mikrobiologicznej. Omówiono wyniki aktualnych kierunków badań dotyczących wykorzystania tej technologii zarówno na etapie obróbki pulpy przed tłoczeniem soku, jak i utrwalania wyrobów gotowych. Badania wskazują, że zastosowanie ultradźwięków może stanowić alternatywę dla innych metod obróbki surowca przed tłoczeniem, a ze względu na nietermiczny charakter procesu nie powoduje poważnej degradacji antocyjanów.

Corresponding author – Adres do korespondencji: Dariusz Piotrowski, The National Institute of Horticultural Research, Horticultural Products Processing Center, 15/17 Rybickiego St., 96-100 Skierniewice, Poland, e-mail: dariusz.piotrowski@inhort.pl, https://orcid.org/0000-0001-6838-9364

INTRODUCTION

Improving the quality of juices and other kinds of beverages (especially the content of valuable natural antioxidants) through the use of modern ultrasonic methods has been a recent challenge for more than 40 years for a growing number of food scientists worldwide. The scope of ultrasound energy applications is wide and includes improving the following processing steps: cooking, cutting, defoaming, deagasing, drying, emulsification, extraction, mixing, thawing [7]. The food industry has become interested in the usage of ultrasound because its action can trigger chemical and physical reactions, enabling a wide range of commercial applications. One of the most popular applications of ultrasound is to optimize the extraction of bioactive substances [10: 18, 19]. Ultrasound treatment procedures are sometimes referred to as "sonication," and in juice production technology they are carried out directly on fruit, fruit pulp or the produced juice to improve production yield, product stability and increase content of bioactive compounds. One of the most recent applications is the use of ultrasound in post-harvest processing of fruits and vegetables, where ultrasound acts as a potential trigger for the synthesis of phenolic compounds (this form of interaction with raw materials will not be considered in this paper). It should be remembered that the indicated group of compounds is determining the quality (chemical, sensory and microbiological) of juices, wines and other fruit products, because the concentration of these compounds directly affects, the quality of the product [1, 4, 12, 14]. Fruit of permanent plants with soft flesh, the seeds of which are in the jelly-like pericarp, are called berry fruits [5], eg currants, gooseberries, grapes, blueberries, cranberries. Andrzej Jarczyk (1933–2022) added that in the industrial classification used in Poland, the presented group also includes: raspberries, blackberries, strawberries and wild strawberries. Berry juices have gained great importance in the category of functional food products, as their consumption reduces the risk of chronic and degenerative diseases. This is due to the high content of antioxidant compounds such as polyphenols, among other anthocyanins, in the raw materials used in production. However, conventional thermal processing reduces the content of these compounds, which is why alternative technologies such as ultrasounds are currently being researched [9: 52]. The search for new non-thermal preservation technologies continues to grow, also because traditional thermal processing can have undesirable effects on the sensory properties of juices and the content of valuable nutritional components.

The purpose of this article is to attempt to systematize selected studies concerning the effect of ultrasound on the content of bioactive compounds in berry fruit juices with references to their quality parameters. By design, this analytical study was prepared using the desk research methodology using a systematic literature review of The Google Scholar database (Google Ireland Limited). The following keywords were used: juice, berries, ultrasound. The publication date criteria used were narrowed to the 2012–2022 range. Towards the introduction of some basic terms, selected printed studies were used.

THE IMPACT OF ULTRASOUND ON THE QUALITY OF BERRY JUICES IN TERMS OF CHEMICAL COMPOSITION, SENSORY AND MICROBIOLOGICAL QUALITY

The content of bioactive substances in berry juices is right after the quality of the raw materials used, the second critical factor affecting the content of bioactive compounds is degree of extraction. In the category of fruit juices, berry juices are usually utilized as components of beverages or other products, since juice without any additives is often too sour or tart to be suitable for consumption without dilution. The quality of such an intermediate must be even better in order for a small additive to adequately fulfil the technological function, as a dye for example. The use of ultrasound in the pressing process of berry juices is an interesting proposal for non-thermal processing of raw materials to obtain high-quality products. Such issues have been addressed in numerous scientific works. These studies indicate that ultrasonic technology has the potential to preserve bioactive compounds and reduce microbial contamination. An example of such an experiment was conducted on blackberry fruit pulp subjected to sonication. Ultrasonic processing was performed by a ultrasonic homogenizer with 20 kHz frequency and 750 W of power, over a period of 10 min. The content of bioactive compounds and antioxidant activity was analyzed in extracted juice. During storage, the juice obtained with ultrasound treatment preserved more than 90% of the anthocyanins and showed a significant reduction in microbial load [9: 48–52]. An interesting approach is to study not only the levels of compounds in the fresh juice, but to demonstrate that health-promoting compounds have been increased in the finished product by pretreatment with ultrasound. An example of this approach is the evaluation of the use of ultrasound in American grapes for its effect on the extractability of the juice and the concentration of phenolic compounds in the juice and the wine produced from those fruits. Sonication of the samples was carried out in an ultrasonic bath with a power of 270 W and a frequency of 40 kHz, ultrasounds exposure times were 0, 3, 5, 7 and 10 minutes, depending on the object. [3: 148–152]. As exemplified by the bayberry juice, all US treatments significantly reduced PPO activity in the treated juice, enzyme involved in browning process. PPO activity decreased by 53.23% and 12.84% at 90 and 181 W/cm2 for 10 min, respectively. A noteworthy fact is that as the intensity or duration of ultrasound increased, the rate of PPO inactivation increased rapidly. [1].

It is also worth noting, what impact on the sensory quality of products have ultrasound treatment. In some studies [2, 9, 11, 13], tests involving a sensory panel are also implemented in parallel with physicochemical measurements. An example of this approach is a study [2] that tested the application of ultrasound with different power densities and exposure times on grape fruit, and then evaluated the effects of these treatments on the total polyphenol content and sensory quality of the juices. Ultrasound processors with a nominal power of 130 W or 750 W (depending on the object) with a fixed frequency of 20 kHz and exposure times of 1, 5 and 10 minutes were used for sonication. In this case, ultrasound increased total polyphenol content by up to 83%, and the treatments

also improved the sensory qualities of the juices, which were indicated as preferred by the sensory panelists [2: 72]. Another case under consideration is the participation of ultrasound in the processing of raw materials, as an aid to enzymes in the juice extraction process. The use of enzymes in the fruit juice process is essential for the production of most fruit juices [4, 12]. An example of work on this topic is an experiment [12] in which the goal was to study the effect of commercially used enzymes and ultrasonic treatment on the extraction efficiency and antioxidant properties of mulberry juice. Incubation of samples for 120 min combined with ultrasonic treatment at 45°C for 60 min cause the highest juice yield and antioxidant content in the final product [12: 11]. Juice preservation and storage is another important factor affecting the quality of the final product. Ultrasonic technology is used in juice pasteurization to reduce microbial contamination and lower the activity of enzymes that oxidize polyphenolic compounds. Ultrasound, as a non-thermal method, can support the processes of berry juice pasteurization allowing to reduce the loss of valuable health-promoting compounds present in raw juice. In a study aimed at evaluating the effect of ultrasound on the physicochemical properties and antioxidant activity of blackberry juice, treatment of the product with ultrasound resulted in a reduction in the number of microorganisms, while its physicochemical properties remained unchanged [11: 3]. The authors' results showed that ultrasonic treatment can preserve blackberry juice without compromising its antioxidant and sensory properties. On the list of studies examples, strongly emphasizing proposed treatments or processing options useful for berry juices are: the potential use of a combination of microwaves and ultrasound to increase the functional value of berry juices [8] or a nonthermal pasteurization created by ultrasound, high pressure and pulsed electric fields [15]. The first study was also performed on blackberry juice. Juice processed with ultrasound showed a significant reduction of microbial contamination, in line with the observations of other authors [9: 52]. Another paper describes a study of the effects of various process parameters of ultrasound treatment, aimed at inactivation of *Botrytis cinerea* mold in red grape juice. The study also considered the effect on quality parameters during storage. The best results in reducing microbial contamination were obtained in a facility combining ultrasound with the addition of natamycin. Very importantly, no significant changes in pH, titratable acidity, extract values, color changes and sensory values were observed during the storage period. The equivalent nonthermal pasteurization approaches (ultrasound, high pressure, and pulsed electric fields) proposed strawberry juice resulted with a relevant comparison of three technologies in terms of microbial quality (reduction of the initial microbial population *E. coli* inactivation to an acceptable level), physicochemical properties, and phytochemical characteristics. Processed strawberry juice in the sonicator (at 517.1 mW/mL acoustic energy density, 24 kHz frequency, temperature increase up to 55.1°C after a come-up time of 4 min) obtained phytochemical retention after processing represented in changes in percentage on following levels: total phenolic content TPC: -0.2%, total anthocyanin content TAC: 8.9% and radical scavenging activity RSA: 17.3% [15].

The combined use of natamycin and ultrasound proved to be effective in reducing *Botrytis cinerea* contamination without causing a loss of juice quality [14]. A similar pattern was followed in a study that undertook to find levels of ultrasound and the addition of pomegranate extract and geraniol to optimize the preservation of strawberry juice. The optimal combination consisted of 0.15 µL/mL geraniol, 360 µg/mL pomegranate extract and 30 min of ultrasound treatment. This treatment was able to significantly reduce microbial contamination, with a low impact on sensory attributes, while improving the antioxidant activity of the product compared to untreated juice samples. In addition, it reduced *E. coli* contamination to undetectable values. In this way, the optimized treatment allowed for an extended shelf life and significantly improved the safety of the strawberry juice [13: 17]. Similar results were obtained in a study, which evaluated the effect of ultrasonic treatment on the physicochemical properties, polyphenol and anthocyanin content, antioxidant capacity and microbiological stability of blackberry juice. The results showed that the pH and extract content increased in juice obtained with ultrasounds usage, compared to conventionally pasteurized juice and raw juice produced without treatment. The treatment lasted 10 minutes, and a frequency of 20 KHz was applied. Similarly positive for the object treated with ultrasound are the differences found in the parameters of color, polyphenol content and antioxidant activity. The authors emphasize the potential of the method and declare that the application of ultrasonic treatment can be used to obtain a functional beverage for human consumption, which retains its sensory characteristics after one month of storage [9: 48-52]. Among the studies considering the impact of this technology on the content of health-promoting compounds, there are also examples in which the authors focused on the stability of vitamins during the storage period of products. The purpose of one work was to evaluate the effect of ultrasonic treatments on the total content of *L*-ascorbic acid and on selected physicochemical characteristics of grape juice during storage. In this publication, samples sonicated and stored for 17 days had a higher L ascorbic acid content than samples prepared by the traditional method [6: 1259].

SUMMARY

Based on the presented research, it can be summarized that the use of ultrasound both at the stage of juice production and its preservation has a beneficial effect on the quality of the obtained products. The use of this method makes it possible to reduce the temperature of the process, which enable to preserve the value of the products and its sensory characteristics. However, it should be remembered that not all laboratory observations are consistent with the literature data presented above. It is possible to allege experiments with conclusions indicating that ultrasound has no effect or a negative effect on the quality of juices. The scientific teams working on ultrasounds application in food production are using variety of equipment and other experimental schemes. Those differences have impact on the content of bioactive compounds in obtained products, hence the conclusions may vary. The technology does not always lead to increased extraction or product stability. Interesting example is a paper discussing a case in which grape fruits of the 'Cabernet Sauvignon' variety were treated with ultrasound in various combinations. However, the observed effects varied depending on the combination [3: 152].

Part of the ultrasound treatments did not show positive results in terms of the concentration of bioactive compounds, and even promoted the degradation of anthocyanins at a significant level. An increase in anthocyanin content in juice as a result of US application in grapes was observed only in the harvest of a given season and more significantly in samples with a higher storage period. In these samples, the observed ranges of increase vary between 15%-25%, compared to control with the same storage period. Such observations make it clear that the application aspect of this technology has great potential; however, it needs more thorough research to become more predictable and controllable.

PODSUMOWANIE

Na podstawie przedstawionych badań można stwierdzić, że zastosowanie ultradźwięków zarówno na etapie produkcji soku jak i jego utrwalania ma korzystny wpływ na jakość otrzymywanych produktów. Zastosowanie tej metody umożliwia obniżenie temperatury procesu, co sprzyja zachowaniu wartości produktów i ich cech sensorycznych. Pamiętać należy jednak, że nie wszystkie badania laboratoryjne są zgodne z przedstawionymi powyżej danymi literaturowymi. Natknąć się można na doświadczenia zakończone wnioskami wskazującymi na brak wpływu bądź negatywny wpływ ultradźwięków na jakość soków. Pewne jest, że zespoły naukowe pracujące nad tym zagadnieniem stosują różnorodne urządzenia oraz inne schematy doświadczeń, więc wpływ ultradźwięków na zawartość związków bioaktywnych może być zróżnicowany. Nie zawsze technologia ta prowadzi do zwiększenia ekstrakcji czy stabilności produktów. Zachęcającym przykładem jest praca omawiająca przypadek, w którym owoce winogron odmiany ‚Cabernet Sauvignon' traktowano ultradźwiękami w różnych kombinacjach. Obserwowane efekty były jednak zróżnicowane w zależności od kombinacji [3: 152]. Większość zabiegów oddziaływania ultradźwięków nie wykazała pozytywnych rezultatów w zakresie stężenia związków bioaktywnych, a nawet sprzyjała degradacji antocyjanów na znacznym poziomie.

REFERENCES

[1] **CAO X., C. CAI, Y. WANG, X. ZHENG. 2019.** "Effects of ultrasound processing on physicochemical parameters, antioxidants, and color quality of bayberry juice." Journal of Food Quality (7917419): 12 pages. https://doi.org/10.1155/2019/7917419.

[2] **COMARELLA, C. G., C.K. SAUTTER, L.C. EBERT, N.G. PENNA. 2012.** "Polifenóis totais e avaliação sensorial de suco de uvas Isabel tratadas com ultrassom. (Phenolic compounds and sensory evaluation of juice from Isabel grapes treated with ultrasound.)" Brazilian Journal of Food Technology 15(May): 69–73. https://10.1590/S1981-67232012005000042.

[3] **COMARELLA C.G., C.K. SAUTTER, M.F. DOSSIN, N.G. PENNA. 2018.** "Ultrasound in the postharvest treatment of grapes: Impact on the extractability and phenolic composition of juice and wine." Semina:Ciencias Agrarias 39(1): 143–156. Access 4.08.2022: https://www.redalyc.org/journal/4457/445760069012/445760069012.pdf

[4] **KIDOŃ M., G NARASIMHAN. 2022.** "Effect of ultrasound and enzymatic mash treatment on bioactive compounds and antioxidant capacity of black, red and white currant juices". Molecules 27(1): 318. https://10.3390/molecules27010318.

[5] **LEKSYKON. 2008.** Leksykon nauki o żywności i żywieniu człowieka oraz polsko-angielski słownik terminów. (Lexicon of food science and human nutrition and a Polish-English dictionary of terms.). Pod red. Piotra P. Lewickiego, Warszawa: Wydawnictwo SGGW: 316.

[6] **LUPU M.I., C.L. BADARAU, V. PADUREANU, C.M. CANJA. 2019.** "Effects of thermal and ultrasound treatments on L ascorbic acid of grapes juice." Revista de Chimie 70(4): 1258–1261. DOI: 10.37358/rc.19.4.7104.

REFERENCES

[1] **CAO X., C. CAI, Y. WANG, X. ZHENG. 2019.** "Effects of ultrasound processing on physicochemical parameters, antioxidants, and color quality of bayberry juice." Journal of Food Quality (7917419): 12 pages. https://doi.org/10.1155/2019/7917419.

[2] **COMARELLA, C. G., C.K. SAUTTER, L.C. EBERT, N.G. PENNA. 2012.** "Polifenois totais e avaliacao sensorial de suco de uvas Isabel tratadas com ultrassom. (Phenolic compounds and sensory evaluation of juice from Isabel grapes treated with ultrasound.)" Brazilian Journal of Food Technology 15(May): 69–73. https://10.1590/S1981-67232012005000042.

[3] **COMARELLA C.G., C.K. SAUTTER, M.F. DOSSIN, N.G. PENNA. 2018.** "Ultrasound in the postharvest treatment of grapes: Impact on the extractability and phenolic composition of juice and wine." Semina:Ciencias Agrarias 39(1): 143–156. Access 4.08.2022: https://www.redalyc.org/journal/4457/445760069012/445760069012.pdf

[4] **KIDON M., G NARASIMHAN. 2022.** "Effect of ultrasound and enzymatic mash treatment on bioactive compounds and antioxidant capacity of black, red and white currant juices". Molecules 27(1): 318. https://10.3390/molecules27010318.

[5] **LEKSYKON. 2008.** Leksykon nauki o zywnosci i zywieniu czlowieka oraz polsko-angielski slownik terminow. (Lexicon of food science and human nutrition and a Polish-English dictionary of terms.). Pod red. Piotra P. Lewickiego, Warszawa: Wydawnictwo SGGW: 316.

[6] **LUPU M.I., C.L. BADARAU, V. PADUREANU, C.M. CANJA. 2019.** "Effects of thermal and ultrasound treatments on L ascorbic acid of grapes juice." Revista de Chimie 70(4): 1258–1261. DOI: 10.37358/rc.19.4.7104.

[7] **MASON T.J., L. PANIWNYK, F. CHEMAT, M.A. VIAN. 2011.** Ultrasonic Food Processing. Chapter 10 in: Alternatives to Conventional Food Processing. Ed. Andrew Proctor. Cambridge: RCS Publishing: 387–414. https://10.1039/9781849730976-00387.

[8] **PÉREZ-GRIJALVA B., J.C. GARCÍA-ZEBADÚA, V.M. RUÍZ-PÉREZ, D.I. TÉLLEZ-MEDINA, S. GARCÍA-PINILLA, R.I. GUZMÁN-GERÓNIMO, R. MORA-ESCOBEDO. 2018.** "Biofunctionality, colorimetric coefficients and microbiological stability of blackberry (Rubus fructicosus var. Himalaya) juice under microwave/ultrasound processing." Revista Mexicana de Ingeniera Quimica 17(1): 13–28.

[9] **PÉREZ-GRIJALVA, B., M. HERRERA-SOTERO, R. MORA-ESCOBEDO, J.C. ZEBADÚA-GARCÍA, E. SILVA-HERNÁNDEZ, R. OLIART-ROS, C. PÉREZ-CRUZ, R. GUZMÁN-GERÓNIMO. 2018.** "Effect of microwaves and ultrasound on bioactive compounds and microbiological quality of blackberry juice." LWT – Food Science and Technology 87: 47–53. https://10.1016/j.lwt.2017.08.059.

[10] **PRIYADARSHINI A., G. RAJAURIA, C.P. O'DONNELL, B.K. TIWARI. 2019.** "Emerging food processing technologies and factors impacting their industrial adoption." Critical Reviews in Food Science and Nutrition 59(19): 3082–3101. https://10.1080/10408398.2018.1483890.

[11] **RAMÍREZ-MORENO E., Q.Y. ZAFRA-ROJAS, J. ARIAS-RICO, J.A. ARIZA-ORTEGA, E. ALANÍS-GARCÍA, N. CRUZ-CANSINO. 2018.** "Effect of ultrasound on microbiological load and antioxidant properties of blackberry juice." Journal of Food Processing and Preservation 42(2): https://doi.org/10.1111/jfpp.13489.

[12] **TCHABO W., Y. MA, F.N. ENGMANN, H. ZHANG. 2015.** "Ultrasound-assisted enzymatic extraction (UAEE) of phytochemical compounds from mulberry (*Morus nigra*) must and optimization study using response surface methodology." Industrial Crops and Products 63(January): 214–225. https://10.1016/j.indcrop.2014.09.053.

[13] **TOMADONI, B., L. CASSANI, M.D.R. MOREIRA, A. PONCE,, M.V. AGÜERO. 2020.** "Natural antimicrobials combined with ultrasound treatments to enhance quality parameters and safety of unpasteurized strawberry juice." International Journal of Fruit Science 20(S2): S178–S197. https://10.1080/15538362.2019.1709115.

[14] **YIKMIS S., H. AKSU. 2020.** "Effects of natamycin and ultrasound treatments on red grape juice." Fresenius Environmental Bulletin 29(2): 1012–1024.

[15] **YILDIZ S., P.R. POKHREL, S. UNLUTURKC, G.V. BARBOSA-CÁNOVAS. 2021.** "Shelf life extension of strawberry juice by equivalent ultrasound, high pressure, and pulsed electric fields processes." Food Research International 140(13): 601–612. https://10.1016/j.foodres.2020.110040.

[7] **MASON T.J., L. PANIWNYK, F. CHEMAT, M.A. VIAN. 2011.** Ultrasonic Food Processing. Chapter 10 in: Alternatives to Conventional Food Processing. Ed. Andrew Proctor. Cambridge: RCS Publishing: 387–414. https://10.1039/9781849730976-00387.

[8] **PEREZ-GRIJALVA B., J.C. GARCIA-ZEBADUA, V.M. RUIZ-PEREZ, D.I. TELLEZ-MEDINA, S. GARCIA-PINILLA, R.I. GUZMAN-GERONIMO, R. MORA-ESCOBEDO. 2018.** "Biofunctionality, colorimetric coefficients and microbiological stability of blackberry (Rubus fructicosus var. Himalaya) juice under microwave/ultrasound processing." Revista Mexicana de Ingeniera Quimica 17(1): 13–28.

[9] **PEREZ-GRIJALVA, B., M. HERRERA-SOTERO, R. MORA-ESCOBEDO, J.C. ZEBADUA-GARCIA, E. SILVA-HERNANDEZ, R. OLIART-ROS, C. PEREZ-CRUZ, R. GUZMAN-GERONIMO. 2018.** "Effect of microwaves and ultrasound on bioactive compounds and microbiological quality of blackberry juice." LWT – Food Science and Technology 87: 47–53. https://10.1016/j.lwt.2017.08.059.

[10] **PRIYADARSHINI A., G. RAJAURIA, C.P. O'DONNELL, B.K. TIWARI. 2019.** "Emerging food processing technologies and factors impacting their industrial adoption." Critical Reviews in Food Science and Nutrition 59(19): 3082–3101. https://10.1080/10408398.2018.1483890.

[11] **RAMIREZ-MORENO E., Q.Y. ZAFRA-ROJAS, J. ARIAS-RICO, J.A. ARIZA-ORTEGA, E. ALANIS-GARCIA, N. CRUZ-CANSINO. 2018.** "Effect of ultrasound on microbiological load and antioxidant properties of blackberry juice." Journal of Food Processing and Preservation 42(2): https://doi.org/10.1111/jfpp.13489.

[12] **TCHABO W., Y. MA, F.N. ENGMANN, H. ZHANG. 2015.** "Ultrasound-assisted enzymatic extraction (UAEE) of phytochemical compounds from mulberry (Morus nigra) must and optimization study using response surface methodology." Industrial Crops and Products 63(January): 214–225. https://10.1016/j.indcrop.2014.09.053.

[13] **TOMADONI, B., L. CASSANI, M.D.R. MOREIRA, A. PONCE,, M.V. AGUERO. 2020.** "Natural antimicrobials combined with ultrasound treatments to enhance quality parameters and safety of unpasteurized strawberry juice." International Journal of Fruit Science 20(S2): S178–S197. https://10.1080/15538362.2019.1709115.

[14] **YIKMIS S., H. AKSU. 2020.** "Effects of natamycin and ultrasound treatments on red grape juice." Fresenius Environmental Bulletin 29(2): 1012–1024.

[15] **YILDIZ S., P.R. POKHREL, S. UNLUTURKC, G.V. BARBOSA-CANOVAS. 2021.** "Shelf life extension of strawberry juice by equivalent ultrasound, high pressure, and pulsed electric fields processes." Food Research International 140(13): 601–612. https://10.1016/j.foodres.2020.110040.