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Warsaw, 28.04.2025

Review

of the doctoral dissertation of MSc Zhe Chen
entitled "Application of supercritical carbon dioxide to improve the quality of ready-to-use carrots and pumpkins during storage",
carried out at the Department of Fruit and Vegetable Product Technology, in Prof. Wacław Dąbrowski Institute of Agricultural and Food Biotechnology – State Research Institute, under the supervision of Prof. Krystian Marszałek, DSc, Eng., and Prof. Zhenzhou Zhu from the School of Modern Industry for Selenium Science and Engineering at Wuhan Polytechnic University

The basis for preparing this review is:

– Act of 20 July 2018 – Law on Higher Education and Science (Journal of Laws of 2018, item 1668, as amended).

– doctoral thesis of MSc Zhe Chen entitled "Application of supercritical carbon dioxide to improve the quality of ready-to-use carrots and pumpkins during storage".

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Formal Evaluation of the Doctoral Dissertation

In recent years, consumers increasingly expect products that are convenient, safe, of high quality, and capable of maintaining their nutritional value over extended periods. Convenience foods include, among others, ready-to-eat foods. In this area, there has been a dynamic development in methods for preparing ready-to-eat foods. The food industry has implemented several advanced technologies such as modified atmosphere packaging (MAP), high-pressure processing (HPP), and pulsed electric fields (PEF). One of the modern methods is also the use of supercritical carbon dioxide (SCCD / $SCCO_2$). These technologies help minimize the loss of bioactive compounds (e.g., vitamins and polyphenols), improve microbiological safety, and extend shelf life without the need for intensive thermal treatment that could deteriorate sensory and nutritional quality.

The PhD thesis of MSc Zhe Chen entitled „Application of supercritical carbon dioxide to improve the quality of ready-to-use carrots and pumpkins during storage" was prepared at the Department of Fruit and Vegetable Product Technology, in Prof. Wacław Dąbrowski Institute of Agricultural and Food Biotechnology – State Research Institute. The PhD thesis was prepared under the supervision of Prof. Krystian Marszałek, DSc, Eng., and Prof. Zhenzhou Zhu from the School of Modern Industry for Selenium Science and Engineering at Wuhan Polytechnic University. This work was carried out within the project „Innovative High pressure process to increase the preservation of ready-to-eat Organic FOOD" (Project number: SF-CO/HOFOOD/4/2021, Year: 2020, Call: SUSFOOD ERA-NET), in which Mr. Zhe Chen was the main researcher.

The doctoral dissertation of Mr. Zhe Chen submitted for review includes an abstract in English and Polish language, a table of contents, a list of publications constituting the main achievement of the PhD student, an introduction, a description of the state of knowledge in the field of the dissertation topic and research objectives and hypotheses, methodology, a presentation and discussion of results, conclusions and observations. The author summed up the obtained results with nine final conclusions. The work also includes a bibliography consisting of 161 references, mainly from the last 10 years. Copies of four publications constituting the basis of the doctoral dissertation are also attached. The dissertation is supplemented with statements by co-authors confirming their participation and the nature of the PhD student's participation in their preparation. At the end of the dissertation, a list of the PhD student's scientific achievements is presented, including a list of publications (in total 20, total IF = 115.1 and MNISW/MEiN points of 2160), participation in domestic and foreign conferences in the form of posters (3) and oral presentations (4), a list of patents (2), participation in projects (5) and awards (3).

Substantive Evaluation of the Doctoral Dissertation

The first part of the paper presents an abstract in English and Polish, which covers the scope of the work, briefly presents the most important results, and finally summarizes how SCCD affected the properties during the storage of carrots and pumpkins.

The second chapter presents a list of publications included in the dissertation (one review paper and three research papers):

[P1] Chen Z., Spilimbergo S., Khaneghah M. A., Zhu Z.Z., Marszałek K. (2022). The effect of supercritical carbon dioxide on the physiochemistry, endogenous enzymes, and nutritional composition of fruit and vegetables and its prospects for industrial application: An overview.

Critical Reviews in Food Science and Nutrition, 64(17), 5685-5699. DOI: 10.1080/10408398.2022.2157370. IF_{2022} = 11.2, MNiSW / $MEiN_{2022}$ = 200 pkt.

[P2] Chen Z., Kapusta I., Zhu Z. Z., Marszałek K. (2024). Enzyme activity and nutritional profile of different-sized carrot cubes treated with supercritical carbon dioxide. Postharvest Biology and Technology, 210, 112763. DOI: 10.1016/j.postharvbio.2024.112763. IF_{2024} = 6.4; MNiSW / $MEiN_{2024}$ = 140 pkt.

[P3] Chen Z., Kapusta I., Zhu Z. Z., Marszałek K. (2024). Quality properties and nutritional compounds of fresh-cut pumpkin treated with supercritical carbon dioxide. The Journal of Supercritical Fluids, 206, 106147. DOI: 10.1016/j.supflu.2023.106147. IF_{2024} = 3.4; MNiSW / $MEiN_{2024}$ = 100 pkt.

[P4] Chen Z., Zhu Z. Z., Marszałek K. (2025). Changes in the storage quality of fresh-cut vegetables using supercritical carbon dioxide treatment. Food Chemistry, 465, 142131. DOI: 10.1016/j.foodchem.2024.142131. IF_{2024} = 8.5; MNiSW / $MEiN_{2023}$ = 200 pkt.

The introduction highlights the growing demand for ready-to-eat vegetables with high nutritional value and their convenience. It discusses the global and national production of carrots and pumpkins, emphasizing their richness in bioactive compounds and their susceptibility to spoilage. Traditional heat treatments and high-pressure processing (HPP) methods are mentioned, along with their limitations regarding nutrient loss and texture degradation. Supercritical carbon dioxide (SCCD) is introduced as an innovative, mild method for extending shelf life while preserving nutritional and sensory qualities. Thus, the study aims to evaluate the effect of supercritical carbon dioxide on enzymatic activity, color, carotenoid, sugar profile, phenolic compounds, and antioxidant capacity in freshly cut carrot cubes with varying sizes and pumpkin, as well as their properties during storage.

The literature review is based on the P1 publication and includes a description of supercritical carbon dioxide treatment with theoretical aspects, as well as the generation of SCCD processing with characterisation of the operational systems and solubility of CO_2 in foods. The effect of SCCD processing on microorganisms and enzymes is explained, as well as the inactivation mechanism of microbes and enzymes by SCCD processing. Moreover, the effect of SCCD processing on the phenolic compounds, carotenoids, and antioxidant activity, as well as sugar contents. The issues discussed in the literature section are correctly selected and justify the research topic well. In addition, the division and content of the individual chapters are correct. In my opinion, this part is very well described.

The research hypothesis and purpose are divided into 4 points, and it is to evaluate the impact of supercritical carbon dioxide (SCCD) treatment on the preservation of carrots and pumpkins, with a particular focus on the effect of different raw material sizes. It is hypothesized that SCCD can inhibit oxidative enzyme activities, inhibit microbial growth, and delay the degradation of bioactive compounds such as carotenoids and polyphenols, thereby preserving the nutritional quality of the produce during storage. The objectives of the study include assessing changes in enzyme activity and nutritional profiles, evaluating the physicochemical properties and antioxidant capacities, and explaining the mechanisms by which SCCD maintains the quality of bioactive compounds in carrots and pumpkins during storage. The research plan is clearly illustrated. This indicates a well-thought-out research concept.

The PhD thesis also presents the most important research methods used in preparing the material and conducting the research on 5 pages. Additionally, methodological information has been described in detail in publications, constituting the doctoral thesis. The PhD thesis contains many abbreviations. Although they are explained at the beginning of the chapter, their overuse makes the text difficult to read. In my opinion, the names of the reagents used should be presented without abbreviations, while the numbers written in words and milliliters could be written with abbreviations, which would make reading easier.

In the next chapter (Chapter 4), presented on 12 typewritten pages, the Author presents the most important results and discussion based on publications P2, P3, and P4. In all publications, the PhD student is listed as the first author but not as the corresponding author. The attached declarations of co-authors confirm the significant participation of the PhD student in co-creating the research concept, participation in developing the research methodology, conducting literature data analysis, conducting experimental work with the assistance of the other co-authors, analyzing, visualizing, and discussing the results, drafting and editing the manuscript, as well as addressing reviewers' comments.

In the individual subchapters, the Author presents the obtained results and refers to the available literature in the discussion of the results. Each subchapter focuses on a specific property of carrots and pumpkins, such as color, microbial activity, phenolic content, antioxidant capacity, carotenoids, or sugar content. In this part, the Author refers to Tables and Figures in individual publications, which requires frequent switching between data and text. Additionally, the author introduces many abbreviations, which makes it difficult to understand the content easily (e.g. „During the 3 weeks of storage, PPO and POD activities in PCP were lower compared to UCP…", „Figure 2(a) illustrates that the TPC of SP5, SP4, SP2, and SP1 exhibited a gradual increase as processing parameters elevated, reaching the highest level at

SP5 (P3).”; „Specifically, when the temperature was maintained at 35°C, the DPPH-RSA and ABTS-RSA of SCCD-TC and SCCD TP gradually increased with rising pressure and extended processing time.”; „Compared to UC, the TSC in SC13, SC12, SC11, SC10, SC9, SC4, SC3, SC2 and SC1 was higher. This increase in the TSC in SCCD-TC can be attributed to SCCD processing…”). Moreover, a consolidated list of abbreviations is not provided. However, I would recommend using fewer abbreviations to make the text more understandable to the reader.

Chapter 5 of the doctoral dissertation contains observations and conclusions in the form of 3 points regarding the effect of SCCD on 1. carrot, 2. pumpkin 3. storage.

Detailed Comments on the Doctoral Dissertation

The work contains minor editing errors, typos, etc. (e.g., page 18, paragraph 1, line 8, citing a work by name and not by surname, etc.), which do not affect the substantive value of the work.

The publications that are the basis for applying for a doctoral degree have been previously assessed by journal editors and independent reviewers, but I would like to highlight a few of my observations:

1. publication P2
   - lack of explanation of the abbreviations used for the samples, it should be given in the methodology part instead of the appendix.
2. publication P4
   - for figure 4 it should be used the same scales on the x-axis to easily see what changes occurred before and after SCCD.

To further clarify specific aspects of the dissertation and to encourage scientific discussion, I would like to ask the candidate to address the following questions:

1. Given the importance of sensory analysis in determining the quality and consumer acceptance of food products, has an organoleptic evaluation been conducted on SCCD-treated carrots and pumpkins?
2. In the context of consumer safety and regulatory approval, how does the SCCD process compare with more conventional preservation methods?
3. Based on your findings, what further research directions would you propose to optimize SCCD treatment for other types of vegetables or fruits?

4. How does the SCCD treatment compare to other commonly used food processing techniques, such as high-pressure processing (HPP) or thermal pasteurization, in terms of preserving nutritional quality, enzyme inactivation, and microbial safety in ready-to-eat products?
5. Given the promising results of SCCD treatment, how does the cost of implementing this technique compare to other food processing methods?
6. Could the candidate elaborate on the potential limitations of applying the SCCD technique on a larger industrial scale?
7. To what extent is SCCD technology currently used in the food industry?

To sum up the substantive assessment, I state that Ms. Zhe Chen's achievement consists in examining how supercritical carbon dioxide (SCCD) treatment affects enzyme activity, color, carotenoid and sugar profiles, individual phenolic compounds, and antioxidant capacity in carrot cubes of varying sizes (1 cm and 2 cm) and pumpkins (1 cm) as well as its effect on the storage quality. The mechanism of SCCD on different properties was also explained. The research results were published in journals, whose total Impact Factor (IF) is 29.5 and a total of 640 points according to the MNiSW / MEiN evaluation system.

Final conclusion

The reviewed dissertation by MSc Zhe Chen entitled "Application of supercritical carbon dioxide to improve the quality of ready-to-use carrots and pumpkins during storage" is an experimental study carried out at a very good level. In my opinion, the doctoral dissertation of M.Sc. Zhe Chen meets the requirements for doctoral dissertations for the academic degree of Ph.D, and therefore, I am submitting an application to the scientific council of the Institute of Agro-Food Industry Biotechnology – National Research Institute to admit the candidate to the public defense.

M. Nowacka