Identification of Characteristic Vibration Signal Parameters During Transport of Fruit and Vegetable

Natalia IDASZEWSKA
Institute of Machines and Motor Vehicles Poznan University of Technology, Piotrowo 3, 60-965 Poznań, natalia.idaszewska@put.poznan.pl

Grzegorz M. SZYMAŃSKI
Institute of Combustion Engines and Transport, Poznan University of Technology, Piotrowo 3, 60-965 Poznań, grzegorz.m.szymanski@put.poznan.pl

Abstract

The occuring vibrations during the transport of fruit and vegetables contributes to damage and accelerates their deterioration. In order to protect transported products against negative changes caused by vibrations during transport, it is necessary to know the values of these vibrations. The article presents the identified characteristic parameters of the vibration signal during transport of fruit and vegetables. The experimental investigations of the actual mechanical loads were carried out on various roads during transport by selected vehicles. Vibration spectra that represented the relation between the acceleration amplitudes and the vibration frequencies were obtained and analyzed. The vibration spectral analysis identified characteristic repetitive values of vibration signal parameters.

Keywords: transport of fruit and vegetable, vibrations

1. Introduction

Fruit and vegetables are one of the most popular food products. They play an important role in human food consumption because they are a rich source of vitamins and minerals, fiber and antioxidants. Consumption of fruits and vegetables is an important factor in the prevention of a variety of diseases including heart conditions [1-5], cancer [6-11] gastric diseases [12, 13] as well as metabolism related diseases [13-16].

Increasing consumer awareness and migration of people from different regions of the world cause greater interest in exotic species resulting from the fact of prolonged transport from distant regions of the world. Transporting fruit and vegetables is a difficult task, because these products are living tissue in which life processes take place constantly. These processes result in the development of sensory features desired by the consumer, but at a later stage lead to the deterioration of products, which in turn generates large losses.

A common phenomenon practiced to prolong the durability during their transportation is transport of unripe fruit and vegetable. This practice is caused by the necessity of long transport over long distances, transporting exotic fruit species from distant areas. Transportation of unripe fruit and vegetable prevents adverse changes occurring in fruits and vegetables, deterioration of quality and even damages, which generates financial losses. Fruits and vegetables that are delivered to the region of consumption are frequently subject to forced ripening through the application of ethylene, which completes the process in just a few hours. Such practices may adversely affect some sensory features deteriorating the quality of the produce.

To maintain the highest possible quality of fruits and vegetables during transport, they should be provided with appropriate climate conditions that can slow down the processes that occur, thus protecting them from deterioration. Transport, however, introduces another parameter - vibrations. The occurrence of vibrations contributes to damage in transported products [17, 18]. Vibration that generates constant impacts and rubbing of the neighboring fruits and vegetables leads to the formation of bruises on their surface, which may even lead to juice secretions [19]. This, in turn, initiates the appearance of rotting processes which results in spoilage of the transported load. Vibrations negatively affect on the quality of fruits and vegetables, which, losing their original shape, are not suitable for direct sale, and often for further processing.

Numerous investigations show the negative impact of vibrations on transported fruit and vegetables, which result the form of dents, scratches and rotten spots. However, there is a lack of information on the exact values of vibration parameters, which vary depending on the region in the world where fruit and vegetables are transported. It is therefore necessary to know the exact parameters of the vibration signal when transporting fruit and vegetables on various roads and with different types of vehicles for transporting fruit and vegetables. If the vibrations contribute to the deterioration of products during transport, it can be assumed that their impact on transformations in transported products is as important as the influence of other factors (temperature, humidity). Knowledge about the value of specific vibration parameters may be significant in later determining the impact of these vibrations on the physicochemical parameters of fruits and vegetables, and this in turn can significantly facilitate the decision on the date of harvesting these products depending on the place of their distribution. This could contribute to reducing losses during fruit and vegetable transportation and at the same time help to preserve the best sensory and health features of fruit and vegetables without having to practice subjecting them to forced ripening.

2. Methodology

Within the preliminary investigations, measurements were carried out of the actual vibration during transport of fruits with a Lambert trailers on the distance of approx. 500 km. The trailers were loaded with Europalets with crates filled with 3 kg of fruits each (loose). The fruits were loose in the crates. The temperature in the trailer was approx. 5°C. The vibration sensor was fitted in the front of the trailer on the bottom of the highest placed crate. Upon loading the trailer, the vibration recorder was initiated. The recording lasted for 7 hours in each vehicle. After the trailer was filled with load, the vibration recorder was started to record. The recording was carried out for the next 7 hours, determined by the recorder's battery life. The computer program for recording vibrations was set in such a way that the recording was divided into 7 1-hour-long sections. The data were saved on a memory card located in the recorder, and their reading was possible after returning the vehicle to the place where the measurements began. The measurement was made on three different vehicles when they were stationary (refrigeration unit switched on) described STOP and on two different roads. To measure the vibration signal parameters occurring during road transport, a measuring system was used, the diagram of which is shown in Figure 1.

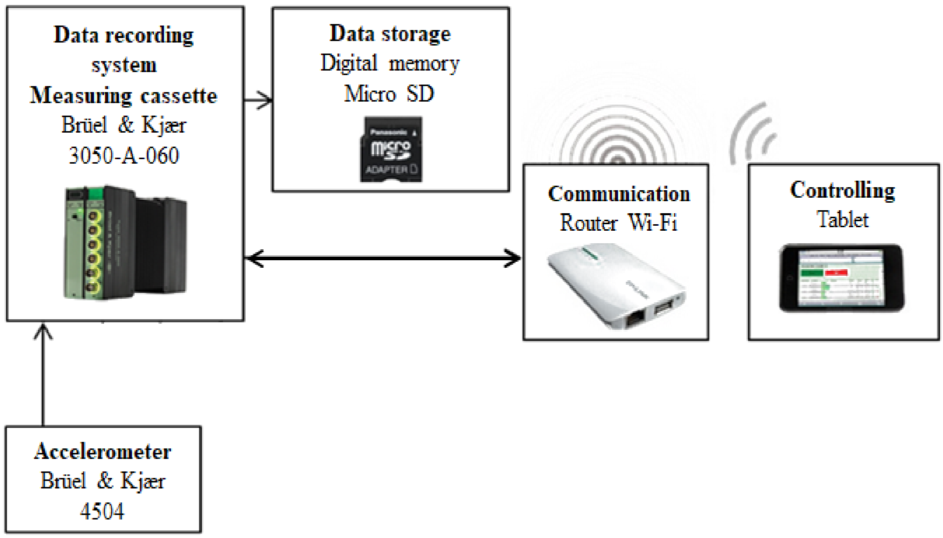

Figure 1. Diagram of the vibration measurement stand

The measurements system was composed of transducer (type 4504) connected to a wi-fi router and a battery-powered vibration recorder (LAN-XI Notar) capable of storing the recorded data on a flash memory card. The recorder was initiated via wi-fi from a portable computer. The computer had PULSE system data acquisition software. The transducer, the data recorder and the software were manufactured by Brüel&Kjær. Vibrations in the vertical direction were recorded. Since these are the first such tests at the Institute of Machines and Motor Vehicles, no tests related to vibration transmittance have been performed.

3. Analysis of results

Based on the investigations of the vibration signals carried out in actual traffic, vibration frequencies were assessed that dominate in the vibration signals during the transport of fruits. The recorded vibration signals shown in Figure 2 were subjected to time-frequency analysis and frequency analysis using the assumptions of the Fourier transform.

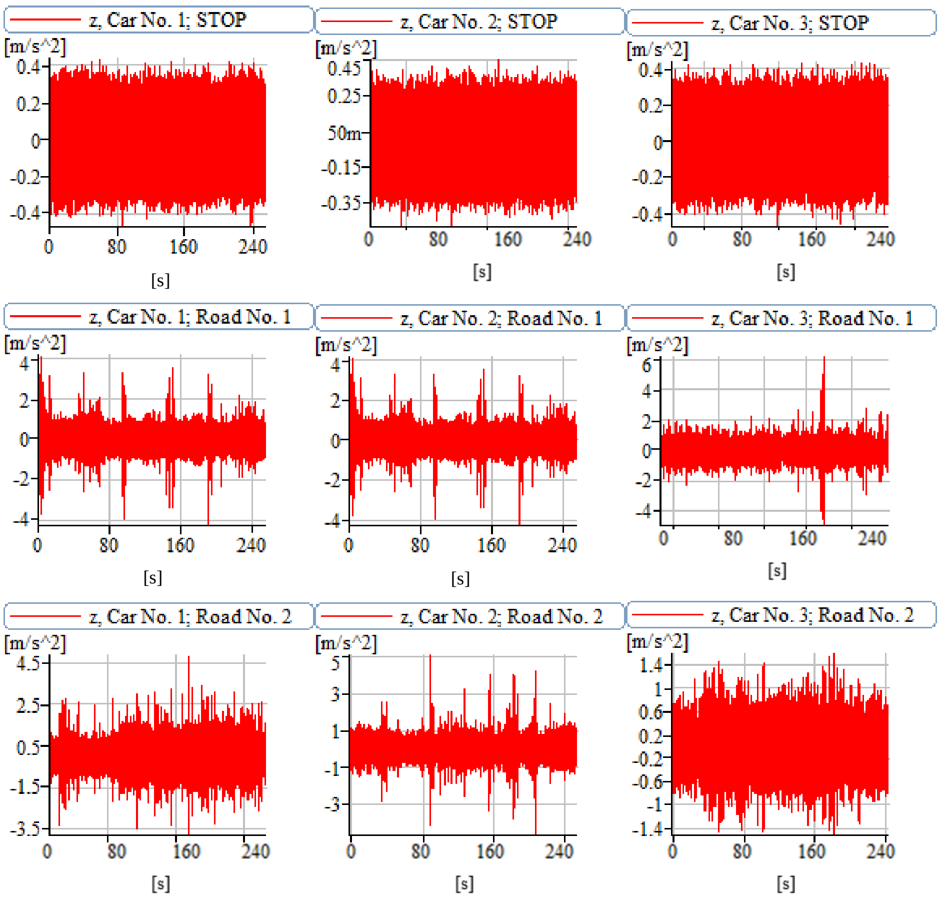

Figure 2. Time history of vibration recorded during the transport under actual traffic conditions for different vehicles when they were stationary (only refrigeration unit switched on) described STOP and on two different roads

Based on the waveforms shown in Fig. 2, the signals were found to be non-stationary. Therefore, time-frequency analysis (STFT) was performed to check amplitude and frequency stationarity. The STFT result can be treated as a series of spectra determined for local, short time segments of time history [20].

$$STFT\left[x_w(t,\tau)\right] = X_w(f,\tau) = \int_{-\infty}^{\infty} w(t,\tau)\,x(t)\cdot e^{-i2\Pi ft}\,dt \tag{1}$$

where: $x(t)$ – time course representing analyzed input signal; $w(t)$ – time window function (tapering function); τ – position of time window in time domain.

The results of the STFT analysis are presented in Fig. 3.

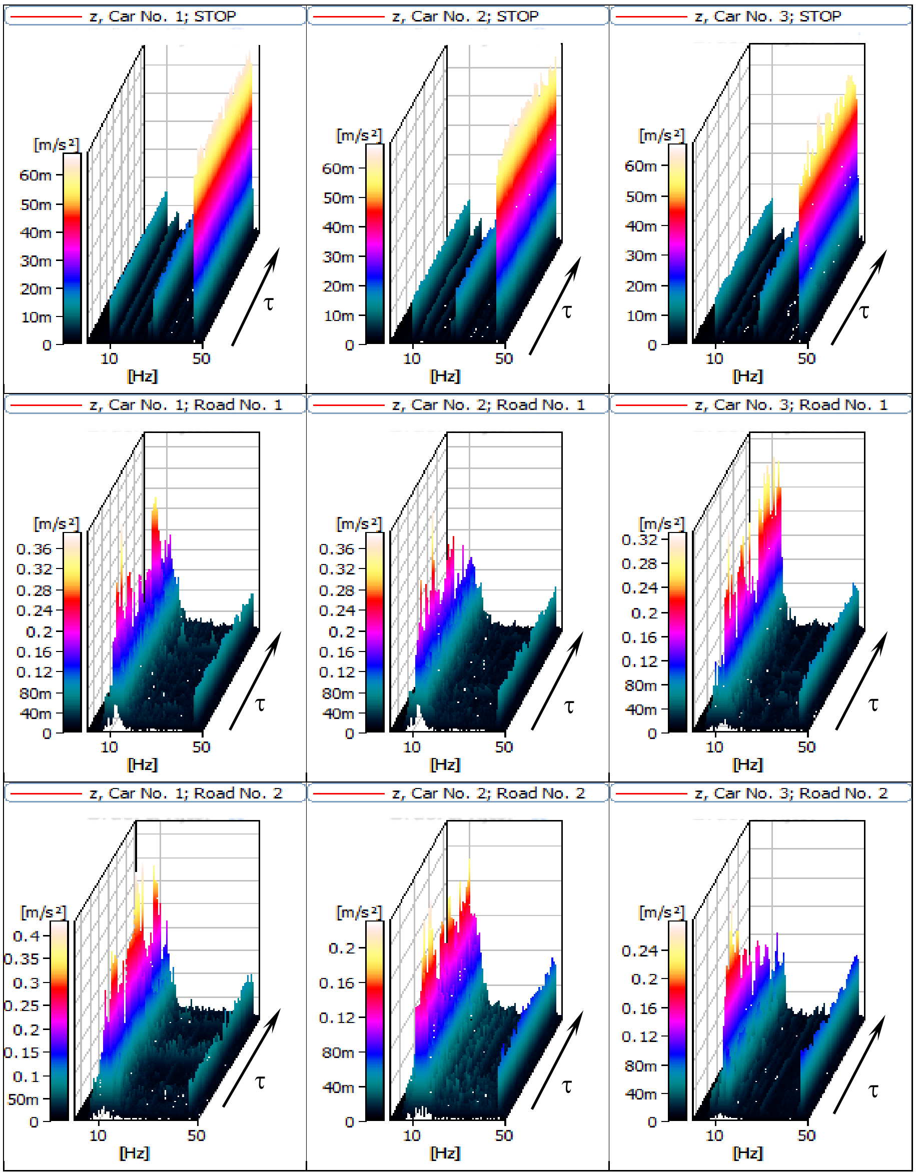

Figure 3. Results of time-frequency analysis during the transport under actual traffic conditions for different vehicles when they were stationary (only refrigeration unit switched on) described STOP and on two different roads

Based on the STFT on Fig. 3 it was found that there are characteristic vibration frequency bands generated during transport of fruit and vegetables. Figure 4 presents the FFT spectrum of the vibration recorded during the transport of the fruits.

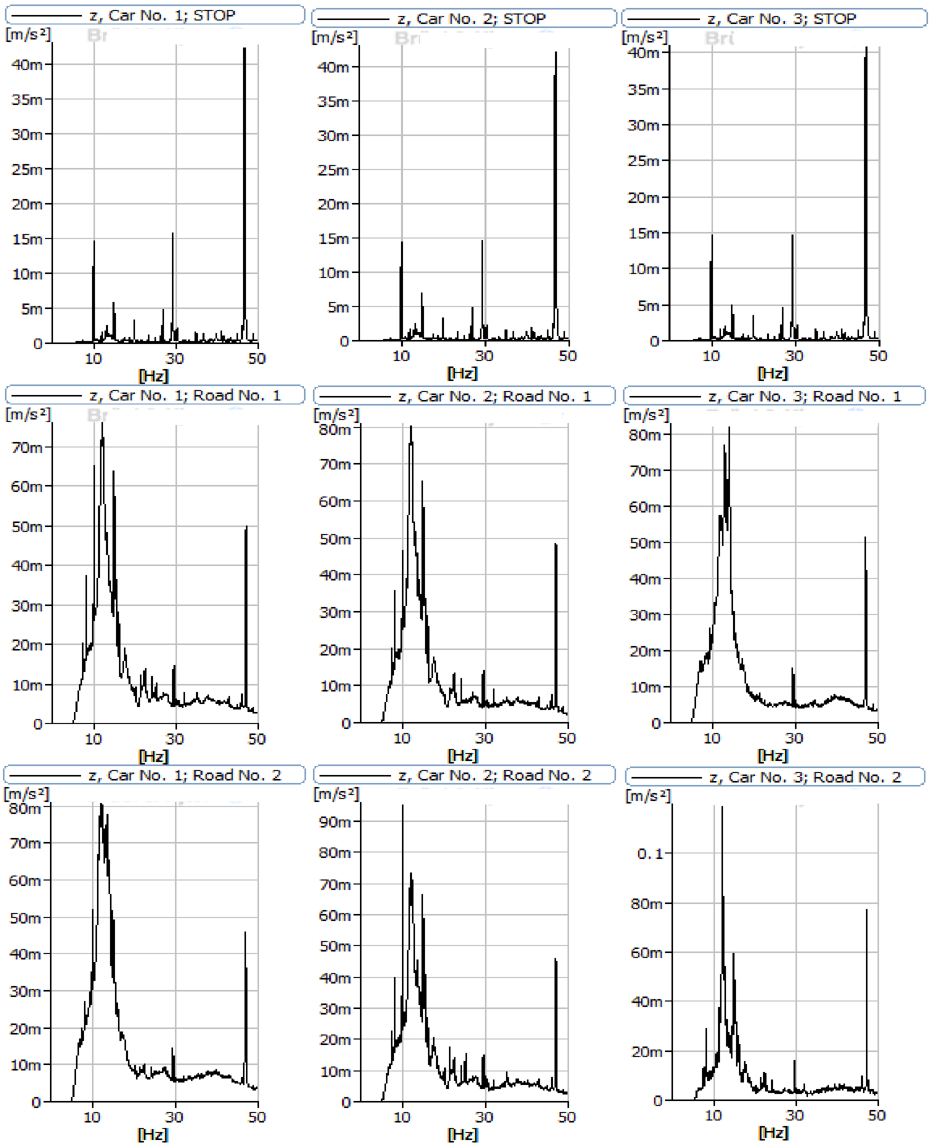

Figure 4. Results of FFT analysis for signals recorded during the transport under actual traffic conditions for different vehicles when they were stationary (only refrigeration unit switched on) described STOP and on two different roads

Based on spectrum analysis, the characteristic vibration frequencies were estimated:

- for the STOP case: 10 Hz, 29 Hz, 47 Hz.
- for the Car No. 1; Road No. 1 case: 12.25 Hz, 29 Hz, 47 Hz,

- for the Car No. 2; Road No. 1 case: 12.25 Hz, 29 Hz, 47 Hz,
- for the Car No. 3; Road No. 1 case: 14 Hz, 29 Hz, 47 Hz,
- for the Car No. 1; Road No. 2 case: 12.25 Hz, 29 Hz, 47 Hz,
- for the Car No. 2; Road No. 2 case: 12.25 Hz, 29 Hz, 47 Hz,
- for the Car No. 3; Road No. 2 case: 12,25 Hz, 29 Hz, 47 Hz.

3. Using of identified parameters of vibration signals

Based on data obtained during experimental tests (during driving time) was estimated by energy supplied to the load for one hour, as a result of vibration processes. Based on the analysis of characteristics in Fig. 4 it was found that the analyzed vibration signals aren't monoharmonic. Therefore, a_{RMS} were estimated for frequency bands with a width of 15 Hz and central frequencies presented in chapter 2.

Knowing the equivalent value of vibration acceleration, the dose of vibration was determined to enable comparison of changes that took place in fruits subjected to vibration of different duration. The vibration dose was determined on the basis of the following relationship [21]:

$$\mathrm{eVDV} = \mathrm{k} \cdot a_{\mathrm{RMS}} \cdot t^{0.25} \tag{2}$$

where: eVDV is Estimated Vibration Dose Value [m/s$^{1.75}$], a_{RMS} is weighted equivalent value of vibration acceleration [m/s^2], t is time [s], k is nominally 1.4 for crest factors below 6.

Figure 5 shows an example of estimating the a_{RMS} value in the frequency band 12.25±7.5 Hz. Delta means the a_{RMS} value of vibration in the marked frequency band.

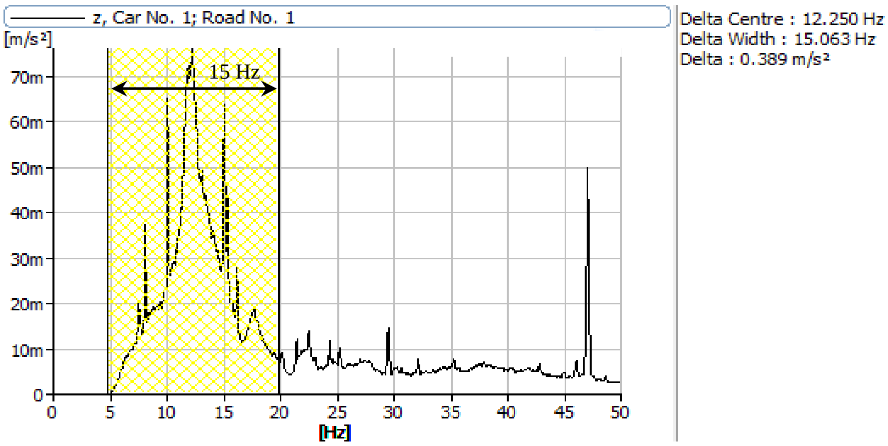

Figure 6. An example of estimating the a_{RMS} value in the frequency band 12.25±7.5 Hz

Tables 1-3 presents the eVDV to the produce depending on the frequencies, acceleration amplitudes and vibration displacement for stationary vehicle and on 2 different roads. EVDV values for all vehicles were very similar, therefore results for only one vehicle (Car 1) were presented.

Table 1. Calculation of Estimated Vibration Dose Value supplied to the produce depending on the frequency; vehicle is stationary; Car 1

	Vibration frequency [Hz]	a_{RMS} [m/s^2]	Time [s]	eVDV [m/s$^{1.75}$]
Vehicle is stationary	10	0.017	3600	0.18
	29	0.021	3600	0.23
	47	0.061	3600	0.66

Table 2. Calculation of Estimated Vibration Dose Value supplied to the produce depending on the frequency; road 1

	Vibration frequency [Hz]	a_{RMS} [m/s^2]	Time [s]	eVDV [m/s$^{1.75}$]
Car 1	12.25	0.389	3600	4.22
	29	0.076	3600	0.82
	47	0.095	3600	1.03
Car 2	12.25	0.395	3600	4.28
	29	0.075	3600	0.81
	47	0.096	3600	1.04
Car 3	12.25	0.415	3600	4.50
	29	0.064	3600	0.69
	47	0.103	3600	1.12

Table 3. Calculation of Estimated Vibration Dose Value supplied to the produce depending on the frequency; road 2

	Vibration frequency [Hz]	a_{RMS} [m/s^2]	Time [s]	eVDV [m/s$^{1.75}$]
Car 1	12.25	0.482	3600	5.23
	29	0.091	3600	0.98
	47	0.111	3600	1.20
Car 2	12.25	0.384	3600	4.16
	29	0.078	3600	0.85
	47	0.092	3600	1.00
Car 3	12.25	0.314	3600	3.41
	29	0.048	3600	0.52
	47	0.106	3600	1.15

6. Conclusions

Based on the investigations of the vibration signals carried out in actual traffic during the transport of fruits in different vehicles and on two different type of road, characteristic and domination vibration frequencies were assessed that dominate in the vibration signals. Based on the spectra obtained, the following values were estimated vibration dose supplied to the produce for one hour. For stationary vehicle the highest eVDV supplied to the produce is about 0.66 m/s$^{1.75}$ for central frequency 47 Hz and the lowest eVDV supplied to the produce is 0.18 m/s$^{1.75}$ for central frequencies 10 Hz. For the road no 1 the highest eVDV supplied to the produce is about 4.50 m/s$^{1.75}$ for central frequencies 12.25 Hz and the eVDV is significantly lower for other frequencies (Car 3). For the road no 2 the highest eVDV supplied to the produce is about 5.23 m/s$^{1.75}$ for central frequencies 12.25 Hz and is lower for other frequencies (Car 1). The lowest eVDV supplied to the produce during transport is about 0.52-0.98 m/s$^{1.75}$ for central frequencies 47 Hz. Based on the results of the research, it will be possible to build a stand for simulation of the process of fruit and vegetable transport in the vibration aspect.

Acknowledgments

The conducted research was subsidized by Ministry of Science and Higher Education 05/51/DSPP/3552.

References

1. L. Dauchet, P. Amouyel, J. Dallongeville, *Fruits, vegetables and coronary heart disease*, Nat. Rev. Cardiol., **6**(9) (2009) 599 – 608.
2. D. Chen, C. Huang, Z. Chen, *A review for the pharmacological effect of lycopene in central nervous system disorders*, Biomed. Pharmacother., **111** (2019) 791 – 801, doi:10.1016/j.biopha.2018.12.151.
3. I. Klein, *Cardiovascular disease and Cardiovascular Disease*, Braunwald's Hear. Dis. - A Textb. Cardiovasc. Med., (2011) 1829 – 1843.
4. L. Ma, Z. Sun, Y. Zeng, M. Luo, J. *Yang, Molecular Mechanism and Health Role of Functional Ingredients in Blueberry for Chronic Disease in Human Beings*, Int. J. Mol. Sci., **19** (2018) 2785, doi:10.3390/ijms19092785.
5. C. N. Zhao, X. Meng, Y. Li, S. Li, Q. Liu, G. Y. Tang, H. Bin Li, *Fruits for prevention and treatment of cardiovascular diseases*, Nutrients., **9** (2017) 1 – 29, doi:10.3390/nu9060598.
6. K. E. Bradbury, P. N. Appleby, T. J. Key, *Fruit, vegetable, and fiber intake in relation to cancer risk: Findings from the European Prospective Investigation into Cancer and Nutrition (EPIC)*, Am. J. Clin. Nutr., **100** (2014) 1 – 4, doi:10.3945/ajcn.113.071357.
7. A. Chothiphirat, K. Nittayaboon, K. Kanokwiroon, T. Srisawat, R. Navakanitworakul, *Anticancer Potential of Fruit Extracts from Vatica diospyroides Symington Type SS and Their Effect on Program Cell Death of Cervical Cancer Cell Lines*, Sci. World J., **2019** (2019) 1 – 9, doi:10.1155/2019/5491904.
8. Y. Jeong, J. W. Lim, H. Kim, *Lycopene Inhibits Reactive Oxygen Species-Mediated NF-κB Signaling and Induces Apoptosis in Pancreatic Cancer Cells*, Nutrients., **11** (2019) 762, doi:10.3390/nu11040762.
9. R. Reiss, J. Johnston, K. Tucker, J. M. DeSesso, C.L. Keen, *Estimation of cancer risks and benefits associated with a potential increased consumption of fruits and vegetables*, Food Chem. Toxicol., **50** (2012) 4421 – 4427.

10. A. R. Vieira, L. Abar, S. Vingeliene, D. S. M. Chan, D. Aune, D. Navarro-Rosenblatt, C. Stevens, D. Greenwood, T. Norat, *Fruits, vegetables and lung cancer risk: A systematic review and meta-analysis*, Ann. Oncol., **27** (2016) 81 – 96, doi:10.1093/annonc/mdv381.
11. J. W. Wang, C. G. Zhang, Q. L. Deng, W. L. Chen, X. Wang, J. M. Yu, *The associations of comorbidities and consumption of fruit and vegetable with quality of life among stomach cancer survivors*, Health Qual. Life Outcomes, **16** (2018) 1 – 7, doi:10.1186/s12955-018-0886-y.
12. J. H. Kim, J. Lee, I. J. Choi, Y.-I. Kim, O. Kwon, H. Kim, J. Kim, *Dietary Carotenoids Intake and the Risk of Gastric Cancer: A Case—Control Study in Korea*, Nutrients., **10** (2018) 1031, doi:10.3390/nu10081031.
13. B. Peleteiro, P. Padrão, C. Castro, A. Ferro, S. Morais, N. Lunet, *Worldwide burden of gastric cancer in 2012 that could have been prevented by increasing fruit and vegetable intake and predictions for 2025*, Br. J. Nutr., **115** (2016) 851 – 859, doi:10.1017/s000711451500522x.
14. W. Brown, I., Rosner, B., Willett, *Cholesterol-lowering effects of dietary fiber: a meta-analysis*, Am. J. Clin. Nutr., **69** (1999) 30 – 42.
15. C. E. Butterworth, *Vitamin safety: a current appraisal*, Vitam. Nutr. Inf. Serv., **5** (1994) 1 – 10.
16. W. Wang, H. Lu, S. Zhang, Z. Yang, *Damage caused by multiple impacts of litchi fruits during vibration harvesting*, Comput. Electron. Agric., **162** (2019) 732 – 738, doi:10.1016/j.compag.2019.04.037.
17. H. M. Jung, S. Lee, W.-H. Lee, B.-K. Cho, S.H. Lee, *Effect of vibration stress on quality of packaged grapes during transportation*, Eng. Agric. Environ. Food., **11** (2018) 79 – 83, doi:10.1016/J.EAEF.2018.02.007.
18. X. Wei, D. Xie, L. Mao, C. Xu, Z. Luo, M. Xia, X. Zhao, X. Han, W. Lu, *Excess water loss induced by simulated transport vibration in postharvest kiwifruit*, Sci. Hortic., **250** (2019) 113 – 120, doi:10.1016/j.scienta.2019.02.009.
19. R. Zhou, X. Wang, Y. Hu, G. Zhang, P. Yang, B. Huang, *Reduction in Hami melon (Cucumis melo var. saccharinus) softening caused by transport vibration by using hot water and shellac coating*, Postharvest Biol. Technol. **110** (2015) 214 – 223, doi:10.1016/j.postharvbio.2015.08.022.
20. R. Barczewski, G. M. Szymański, *Application of the time-frequency selection of the vibration to valve clearance assessment of a diesel engine*, Diagnostyka, **30** (2004) 18 – 22 (in Polish).
21. D. Więckowski, *Analysis domain of the time vertical vibration on account comfort child during ride in the car*, Czasopismo Techniczne, **109** (2012) 73 – 91 (in Polish).