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THE INFLUENCE OF THE PRODUCTION PROCESS MANAGEMENT ON THE HEALTH-PROMOTING PROPERTIES OF SAUERKRAUT

Mateusz Zawadzki
Student Research Club „loGIStic", Gdynia Maritime University, 81-87 Morska St., 81-225 Gdynia, Poland, ORCID 0000-0001-7947-2729, e-mail: mateusz.zawadzki28@wp.pl

Abstract: The article presents the issue of health-promoting properties of sauerkraut based on a critical analysis of literature sources. The issue of the properties of cabbage and sauerkraut is discussed, and the characteristics of the most frequently used species in the pickling process are presented, namely white cabbage (Latin Brassica oleracea var f. Alba). Moreover, the content of water, nutrients and minerals in whitehead cabbage and sauerkraut have been presented and compared, showing their differences. The course of the ensilage process has been discussed, and the lactic acid bacteria mainly responsible for it, *Lactobacillus plantarum,* has been indicated. The author has also pointed to glucosinolates in sauerkraut, which show high anti-cancer activity, primarily preventing the development of breast, prostate, lung and stomach cancer. The influence of the production process on the health-promoting properties of sauerkraut has also been analysed. For these reasons, the aim of the work was to present the Griffin model in the context of the assessment of sauerkraut production process management. Such action made it possible to determine the stages of the production process that should be subject to special control.

Keywords: cabbage, sauerkraut, pickling, antioxidants, Polish superfoods, management.

1. INTRODUCTION

The name cabbage comes from Latin, from the word *caputium*- which, roughly translated, means headdress. Cabbage (Latin *Brassica*) is a herbaceous plant from the cabbage family. Literature sources indicate about 35 to 44 species of it (Warwick). The original areas of occurrence were Euro-Asia and North Africa. However, humankind has spread these plants to other continents.

The cultivation of white-headed cabbage is carried out based on crop rotation. It is a several-year planned cycle of cultivating carefully selected plant species and cultivating them in the proper order year after year. It should be noted that the cabbage has a withdrawal period of four years, after which it can be replanted freely and without detriment to the environment [Anyszka 2013].

The soil on which the cabbage is grown should be wet and humus, i.e. one that is black or brown with fragments of dead plants. This collects the correct amount of air and water, and plants absorb nutrients easily. The cultivation of this vegetable should not take place in sandy loam soils, black soils, loess or riverside wastes. However, peat soil will be the most appropriate for medium-late or late varieties. An unsatisfactory cabbage yield is obtained from areas with high acidity and low molybdenum content. An increased infestation of *brassica syphilis* can be noticed when cultivated on such soil.

Table 1 shows the water, nutrient and mineral content in white-headed cabbage and sauerkraut.

Table 1. Comparison of water, nutrient and mineral content in white headed cabbage and sauerkraut

	White-headed cabbage	**Sauerkraut**
Component	**Amount per 100g of edible parts**	**Amount per 100g of edible parts**
Energy value	33 kcal	16 kcal
Protein	1,7 g	1,1 g
Fat	0,2 g	0,2 g
Total carbohydrates	7,4 g	3,4
Dietary fibre	2,5g	2,1 g
Sodium	19 mg	260 mg
Potassium	228 mg	211 mg
Calcium	67 mg	36 mg
Phosphorus	33 mg	18 mg
Magnesium	13 mg	7 mg
Vitamin A	9 ug	3 ug
β-carotene	52ug	18 ug
Vitamin E	1,67 mg	0 ug
Thiamine	0,072 mg	0,03 mg
Riboflavin	0,06 mg	0,06 mg
Niacin	0,36 mg	0.1 mg
Vitamin C	48 mg	16 mg

Source: Kunachowicz et. al. 2016.

Based on an analysis of the information in Table 1, it should be noted that, in the ensilage process, the energy value of vegetables decreases significantly along with the protein content. The amount of fat remains unchanged. However, the total carbohydrate content drops by 4 g in 100 g of sauerkraut compared to fresh cabbage. A decrease in the amount of dietary fibre can also be noticed. However, the amount of sodium in 100 g of cabbage in the pickling process increases from the base level of 19 mg to as much as 260 mg. This phenomenon can be considered unfavourable since sodium is present mainly in the form of sodium chloride, i.e. table salt.

On the other hand, the amount of salt in the average person's diet is too high and should be limited due to its harmful effects: increasing blood pressure and water accumulating in the body. In turn, the potassium content drops by 17 mg, while the amount of calcium, phosphorus and magnesium drops by almost half. Vitamin A and β-carotene are reduced almost threefold in sauerkraut compared to fresh cabbage. Vitamin E, on the other hand, is not present in sauerkraut, and before the pickling process, it is present in the plant in the amount of approximately 1.67 mg per 100 g of fresh cabbage. The thiamine, niacin and vitamin C content also decreases in the ensilage process [Kunachowicz et al. 2016].

The white cabbage used in pickling (Latin *Brassica oleracea var f. Alba*) is a biennial plant. Therefore, the heads' weight and size depend on the variety (early, medium-early, medium-late, late) and their growth conditions. The most common is the one within a weight range of 0.7–3.0 kg, but it should be noted that late varieties weigh up to 5 kg. Cabbage is highly durable, which makes it perfect for long-term storage [Lempka 1985].

The literature indicates that the most common places for storing cabbage are warehouses with a temperature of 0–0.5°C and air humidity of 85–90% [Lempka 1985].

It should be noted that sauerkraut is one of the dishes rooted in the Polish tradition. In traditional Polish cuisine, sauerkraut is used, e.g. as a stuffing for dumplings. As a result, Poland is one of the leading producers of sauerkraut in Europe and the world. In Europe, Poland ranks fourth among producers of sauerkraut [Satora et al. 2020].

Poles' annual consumption of sauerkraut is about 3 kg per person. However, the consumption rate increases significantly during the autumn and winter. This is probably due to the fact that it is a product very often prepared as a reserve for the winter, but there is also a belief that pickled products are rich in vitamin C and lactic acid, thanks to which they strengthen the body's immunity [Satora et al. 2020].

Fermentation is a metabolic process in which bacteria and/or yeast and their enzymes convert carbohydrates into alcohol or organic acids [Nkhata 2018]. The practice has been used to preserve food since ancient times and is now gaining popularity again due to the growing consumer demand for wellness. Not only does fermentation extend the shelf life of food products; it also changes their organoleptic characteristics, adding an intense aroma and taste. What's more, the fermentation of food products may have health-beneficial properties, such as facilitating the digestion of proteins and carbohydrates, improving the availability of vitamins and minerals, and probiotic effects [Ciska, Honke and Drabińska 2021].

Pickling is one of many ways of food preservation. The pickling process in Poland is often used for cucumbers or cabbage but pickling other vegetables or fruits, such as broad beans, beets, and radishes, has also become increasingly popular. This process is based on lactic acid fermentation carried out by lactic acid bacteria such as *Lactobacillus plantarum* [Schlegel 2003; Zhou et al. 2023].

The process of pickling cabbage is easy. However, it is laborious and time-consuming. Historical sources say that cabbage was most often pickled in the late autumn. For this purpose, plump, compact-headed plants, fresh from the field, were selected. Work began with peeling them from the outer leaves. Then, they were successively shredded and placed in a wide log. Next, the vegetable was salted and tamped to limit the access of oxygen from the outside and remove the oxygen inside the vessel as much as possible. These activities aimed to stimulate the process of spontaneous fermentation and prevent the development of putrefying bacteria. The first fermentation processes occur in the cabbage within a few hours of being salted. In the first phase, this process is very dynamic. It is caused, inter alia, by lactic bacteria (*Leuconostoc mesenteroides*). The first dynamic fermentation process usually takes 2-3 days, during which silage foaming, increased gas production, and decreased pH can be observed. The next stage of ensilage, which usually lasts up to two weeks after salting, is proper lactic acid fermentation, during which there is an intensive multiplication of heterofermentative bacteria (*Lactobacillus brevis*, *Lactobacillus plantarum* and *Pediococcus* sp.). After this process is complete, the sauerkraut is ready to eat [Plengvidhya et al. 2007; Siddeeg et al. 2022; Zhou et al. 2023].

The ensilage process is based on simple decomposing sugars in plant cells into lactic acid (1–1.8%), which, among other things, inhibits the rotting process [Wojdyła and Wichrowska 2014].

The literature indicates that the proper course of ensilage depends on the content of sugars and water in the raw material. Therefore, maintaining the temperature range between 15–20°C in the first days of fermentation is also very important. In addition, it is essential to remove the air. The most popular method of doing so is to whip the cabbage or pour brine on, for example, cucumbers [Siddeeg et al. 2022].

It should be noted that many literature sources indicate that a high-fat diet promotes carcinogenesis, while plant-based foods introduce anti-cancer compounds into the body. Many studies show that cruciferous vegetables, such as cabbage, are a highly abundant source of anti-cancer agents [Śmiechowska, Bartoszek and Namieśnik 2008].

Kusznierewicz et al. (2007) indicated numerous features indicating a high level of biological activity in cabbage, both fresh and sauerkraut. This means that cabbage generally exhibits the ability to:

- modulatie the parameters of estrogen receptors through indoles and phytosterols;
- increase the activity of detoxification enzymes by indoles and isothiocyanates;
- producing antioxidants and isothiocyanates that are involved in the expression of genes influencing the appearance of cancer;
- production of antioxidants such as vitamins C and E, as well as polyphenols and carotenoids;
- demonstrating anti-mutagenic properties related to organic sulphur compounds and the aforementioned antioxidants.

2. ANTI-OXIDATING PROPERTIES

Oxygen is a compound necessary for the functioning of any organism that uses it to sustain life. However, even excessive accumulated oxygen can have a toxic effect on living organisms. Therefore, oxygen molecules that occur in nature are mainly non-reactive. However, when appropriate environmental conditions occur, even non-reactive oxygen molecules can be transformed into reactive forms, such as superoxide anhydride, singlet oxygen, hydroxyl radical or hydrogen peroxide [Stolarzewicz et al. 2013].

It should be noted that ROS (Reactive Oxygen Species) lead to protein damage due to their oxidation process. The amino acid residues of proteins – histidine, tryptophan, methionine and cysteine – are the structures most susceptible to damage by singlet oxygen. However, the components of nucleic acids, i.e. purine, pyrimidine and guanine residues, are also destroyed quite quickly by the action of ROS [Puzanowska-Tarasiewicz, Starczewska and Kuźmicka 2008].

It should be emphasised that the above activities lead to the impairment and degeneration of properly functioning cell structures and entire tissues or organs. Even more unfortunately, it causes the formation and development of neoplasms [Chun et al. 2004].

The literature states that free radicals are formed in food processing, i.e. storage, frying, and smoking. They also arise as a result of the action of ultrasound. Free radicals in the human body undoubtedly increase the risk of developing, for example, Alzheimer's, Parkinson's, cataracts, diabetes and atherosclerosis [Chun et al. 2004].

Sauerkraut, on the other hand, has antioxidant properties, which are associated with the presence of numerous vitamins, in particular vitamins C and E. Its polyphenols and carotenoids also influence the antioxidant properties of sauerkraut. The antioxidant activity of fresh cabbage is relatively low compared to tea or red beet. However, during the ensilage process, the level of antioxidants increases significantly (Chun et al. 2004).

As mentioned above, polyphenols are one of the antioxidant compounds found in sauerkraut. Due to their chemical structure, polyphenols are classified into [Mitek and Gasik 2007; Kapusta-Duch et al. 2017]:
- simple polyphenols (e.g. hydroxybenzoic acids);
- phenylpropanoids (e.g. hydroxycinnamic acids);
- flavonoids (e.g. catechins, quercetins, cyanidins);
- complex compounds, i.e. derivatives of phenols (e.g. theaflavins, melanins).

Szwejda-Grzybowska (2010) pointed out that when it comes to polyphenols, their most valuable source in the case of sauerkraut is juice obtained in the fermentation process. Therefore, if possible, sauerkraut should not be drained before preparing food, and moreover, it should not be rinsed, as this removes nutritious ingredients. Kusznierewicz et al. (2007) found that white cabbage (fresh and sauerkraut) with thermal treatment duration releases substances with antioxidant properties. Thus, it should be noted that cabbage may, to some extent, protect other food ingredients from changes due to thermal oxidation. An excellent example is fat, which is much more resistant to possible changes when exposed to a temperature in the presence of fresh cabbage juice and sauerkraut juice.

Antioxidants contained in fresh cabbage juice and sauerkraut juice can protect cellular DNA against the damaging effects of free radicals. Furthermore, there is information in the literature that cells treated with hydrogen peroxide in a dose that should cause complete DNA degeneration in the presence of cabbage juice definitely have less fragmented genetic material than without the juice environment. Thus, it can be noticed that the cabbage phytocomplex has the ability to protect cells against oxidative stress. Moreover, it intensifies the endogenous mechanisms responsible for repairing damage caused within DNA [Szwejda-Grzybowska 2010].

The carotenoids mentioned above are plant pigments exhibiting lipophilic properties, of which one is particularly notable [Zalega and Szostak-Węgierek 2013]:

- astaxanthin;
- canthaxanthin;
- fucoxanthin;
- lutein;
- lycopene;
- zeaxanthin;
- α-carotene;
- β-carotene;
- β-cryptoxanthin.

Zalega and Szostak-Węgierek (2013) indicate that the presence of β-carotene in sauerkraut depends to a large extent on the amount added to the production of carrots. Carotenoids are characterised by antitumor activity, mainly against lung, laryngeal, pharyngeal and oral cancer. Moreover, a relationship has been demonstrated between the degree of β-carotene consumption and the incidence and rate of oesophagal neoplasms development [Zalega and Szostak-Węgierek 2013].

An important fact is that in both fresh and sauerkraut, there are compounds such as caffeic acid, gallic acid, camferol, apigenin, quercetin or glucosinolates [Patyra, Kowalczyk and Kwiatek 2016].

3. ANTI-CANCER PROPERTIES

Another significant chemical compound present in sauerkraut and showing anti-cancer properties are glucosinolates. Glucosinolates are phytochemicals as well as sulphur-containing glucosides. Their structure includes β-D-glucose, sulphonated oxime and a side chain derived from aliphatic amino acids (Ala, Wal, Leu) and aromatic amino acids (Phe, Tyr) and indole amino acids (Trp).

Figure 1 shows the structural formula of glucosinolates.

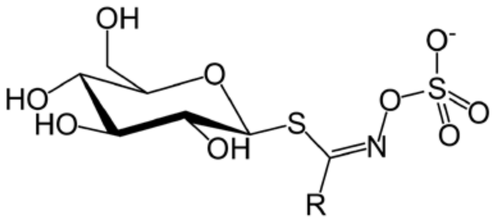

Fig. 1. The structural formula of glucosinolates

Source: Wikimedia (n.d.). Glucosinolate-skeletal. Retrieved June 16, 2022, from https://upload.wikimedia.org/wikipedia/commons/1/13/Glucosinolate-skeletal.png

Numerous scientific studies demonstrate that glucosinolates (GLS) have anti-cancer properties. It was found that the consumption of vegetables containing glucosinolates can protect, to a large extent, the human body against the development of cancer. Due to chemoprevention, the breakdown products of GLS are essential, formed due to myrosin's action, namely isothiacyanins (ITC). Moreover, the breakdown product of glucosinolates is ascorbic. These substances support the processes of regulating the level of transcription factors and the functioning of signalling pathways. Moreover, they participate in a mechanism based on the inhibition of metabolic activation of carcinogens in the first phase of detoxification through cytochrome P450 combined with an increase in enzyme activity. By contrast, the second detoxification phase is responsible for removing xenobiotics [Mithen 2001].

However, it should be emphasised that even positive substances consumed in excess can lead to adverse effects. For example, in the case of glucosinolates, their excess can even lead to a significant impairment of the secretory function of the thyroid gland. This, in turn, gradually leads to an increase in thyroid-stimulating activity and even thyroid hyperplasia. However, this situation can be prevented if glucosinolate-rich vegetables are consumed with iodine-containing products [Patyra, Kowalczyk and Kwiatek 2016].

4. THE SAUERKRAUT PRODUCTION PROCESS

There are two methods of implementing the fermentation process. The first method occurs spontaneously with the aid of the natural bacterial population found in the raw material. The second method involves using selected lactic acid bacteria as inoculants. By using starter cultures, the fermentation process can be controlled, whereas the spontaneous process offers limited control over the quality and safety of the final product. Additionally, the addition of spices or other additives during fermentation can alter the conditions and potentially impact the levels of certain endogenous compounds, such as biogenic amines, in the final product [Majcherczyk and Surówka 2019].

The sauerkraut production process analysed is shown in Figure 2. It is not a complicated process but it is relatively long-lasting. The first stage of sauerkraut production is the selection and possible disposal of raw materials that do not meet quality requirements. Cabbage heads must be green, fresh and firm. They cannot contain mould, and they should be undamaged and healthy. When the raw materials are accepted and intended for the production process, the heads of the cabbage are cleaned, and then the outer leaves are removed. Such action is to ensure that no undesirable microorganisms get into further production. Moreover, the outer leaves are usually damaged or dried, which could deteriorate the quality of the finished silage [Peñas, Martinez-Villaluenga and Frias 2017; Siddeeg et al. 2023].

In the next step, the cleaned cabbage is chopped and then salted in a sodium chloride solution with a 0.7–2.5% concentration. Finally, the cabbage is kneaded to remove excess air and then left to ferment. In Poland, during salting, finely chopped carrots and spices, i.e. pepper, and bay leaf, are also added to the cabbage [Peñas, Martinez-Villaluenga and Frias 2017; Siddeeg et al. 2023].

One of the most critical steps in sauerkraut production is adding salt, as the quantity used has a significant impact on the type and extent of microbial growth and the sensory characteristics of the final product. The addition of salt restricts the activities of Gram-negative bacteria, promoting the development of lactic acid bacteria. As salt concentrations rise, microbial populations and metabolites decrease. Conversely, high salt concentrations can delay sauerkraut maturation and halt the metabolism of LAB. Adding a starting culture of bacteria has recently been shown to be beneficial for industrial sauerkraut production, whereas traditionally, the product is made at home or in small-scale facilities by spontaneous fermentation of indigenous bacteria present in raw cabbage [Thakur and Kabir 2015; Ciska, Honke and Drabińska 2021].

The fermentation process can be carried out spontaneously or induced. In the case of the spontaneous process, the sauerkraut is packaged, and the fermentation process takes place gradually during storage. In the case of the induced fermentation process, it is necessary to add starter cultures, thanks to which the fermentation proceeds much faster. Sauerkraut may be pasteurised before storage but this is not an essential requirement. Pasteurisation leads to the denaturation of microorganisms responsible for the fermentation process, so this treatment can be carried out when fermentation has been completed [Peñas, Martinez-Villaluenga and Frias 2017; Siddeeg et al. 2023].

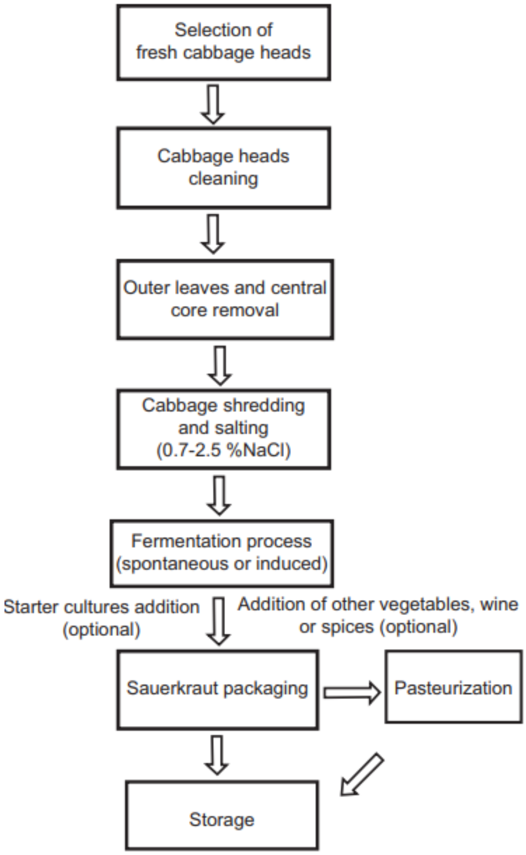

Fig. 2. Sauerkraut production process

Source: Peñas, Martinez-Villaluenga and Frias 2017.

The sauerkraut production process significantly impacts the sensory quality of the finished product and its health-promoting properties. Therefore, it is necessary to manage this process, including methods of maintaining the appropriate standards of hygiene and avoiding possible risks.

According to Griffin's concept, the management process should consist of four essential elements: planning, organising, motivating and controlling [Griffin 2017]. In the case of sauerkraut production process management, the first two elements seem to be the most important in the context of its health-promoting properties. However, in reality, all elements are essential.

Planning should be done in accordance with the actual production demand; no stock of these products should be made. For example, vegetables should always be bought fresh because the amount of health-promoting substances decreases with the storage time. Moreover, they should be domestic vegetables. In the literature, there are reports on the impact of improper storage conditions and long-term transport on the decrease in antioxidant and vitamin content in fruit and vegetables [Pukszta and Platta 2017].

The planning process should also include the purchase of vegetables from reliable producers. Vegetables should come from crops where no prohibited substances are used and vegetables do not contain excessive amounts of nitrites as excess nitrites can reduce food safety. Of course, there are methods to reduce the nitrite content in cabbage by adding appropriate strains of lactic acid bacteria to the fermentation process, which breaks down nitrites. However, it seems more rational to buy vegetables that are not burdened with such a problem [Ren et al. 2016].

The organisational process should be primarily related to implementing practices designed to ensure food safety. In the case of the sauerkraut production process, it is necessary to implement the GMP, GHP and HACCP systems, as it is not primary production. However, research conducted in 2009 concluded that not all manufacturers were aware of the importance of these systems or the need to record all possible production data to enable possible detection of errors. Respondents did not see the need to monitor parameters during the fermentation process; even if they did check them, they did not see the need to record them. One of the respondents even said it could be seen at a glance whether the cabbage was rotten, and no examination was necessary: it becomes soft and turns grey. Therefore, there is a need to disseminate knowledge on the use of appropriate hygienic practices in the production of sauerkraut [Jevšnik, Hlebec and Raspor 2009].

The motivation described by Griffin was primarily related to the context of managing organisations. In the case of process management, motivating employees involved in production is also vital. Employees should be adequately compensated for their commitment to their work. It is also good to regularly organise training in the field of hygiene at the workplace for employees.

The controlling process is directly related to monitoring production process parameters, which should be carried out systematically and rationally. Monitored parameters should always be recorded in appropriate documents. Controlling is also related to assessing the quality of the finished product. This can be done using sensory evaluation and physicochemical measurements, for example.

Controlling the storage conditions of the finished product is also very important as the fermentation process depends on them, as well as the above-mentioned content of health-promoting ingredients. For example, pasteurised sauerkraut stored at 5, 10 and 15°C was subject to other changes in terms of properties, i.e. the content of vitamin C and lactic acid. The lowest losses of vitamin C were recorded in the sample stored at 10°C. This indicates that the product, i.e. sauerkraut, should not be stored at too low or too high a temperature [Wojdyła and Wichrowska 2014].

The pasteurisation process certainly extends the usefulness of sauerkraut, and it is intended to destroy undesirable vegetative microorganisms in the product that could affect its quality. However, in the case of sauerkraut, sterilisation is not recommended due to possible changes in the product's structure and excessive energy consumption and, at the same time, the lack of a measurable effect. Because in the case of acidic food, sterilisation is not required because spore-forming bacteria do not develop there [Wojdyła and Wichrowska 2014]. In addition, due to too long heating at high temperatures in sauerkraut, the content of health-promoting substances, i.e. polyphenols, decreases [Tynek and Papiernik 2005].

Packaging also seems to be a very important factor determining the quality of sauerkraut. Storage of sauerkraut in refrigeration conditions for 4 months caused a significant decrease in the content of the tested components. The average content of vitamin C decreased by 52.6%, and total polyphenols by 32.7%, and their antioxidant activity decreased by 24.4%, regardless of the type of packaging. It also turned out that the type of packaging had no significant effect on the content of vitamin C and total polyphenols. On the other hand, the antioxidant activity of sauerkraut stored in PET met/PE bags was higher than in PELD bags. As a result, the research results indicate that the most appropriate packaging for storing sauerkraut is a laminated bag made of metallised polyethylene terephthalate (PET met/PE) with the addition of polyethylene. Still, further research is needed to evaluate other aspects such as different storage times, different packaging materials, additional technologies and other factors that may affect the quality of stored sauerkraut [Kapusta-Duch et al. 2017].

It follows from the above considerations that sauerkraut is a sensorially attractive product with health-promoting properties. It has a significant nutritional value and is rich in vitamin C, group B vitamins and minerals, including manganese, zinc, calcium, potassium, iron and sulphur. Moreover, sauerkraut is a good source of fibre. There is now abundant scientific evidence that consuming sauerkraut has numerous health benefits, including ingredients that have antioxidant and anti-cancer properties and also soothe inflammation and DNA damage.

The health-promoting properties of sauerkraut can be attributed to the high content of bioactive ingredients, especially the breakdown products of glucosinolates. Glucosinolates and their breakdown products, according to the scientific literature, show high anti-tumour activity, primarily preventing the development of breast, prostate, lung and stomach cancer.

Unfortunately, there are currently few clinical trials assessing the level of influence of the consumption of sauerkraut on the daily functioning of the human body, and the data presented above come mainly from laboratory tests. It should be noted that having a specific ingredient is not synonymous with its absorption and proper use by the body. Therefore, it is necessary to undertake clinical trials to determine the real impact of sauerkraut on the human body. Moreover, such research would make it possible to reliably show the properties of this product and its usefulness in preventing civilisation diseases.

5. CONCLUSIONS

Sauerkraut can be an excellent product if its nutritional values are maintained at the highest possible level. Not only does its nutritional value result from dietary nutritional values but also from health-promoting substances, i.e. anti-cancer and antioxidant substances. However, if the production or storage process is managed incorrectly, the product may lose its properties and become valuable only in terms of nutrition, without pro-health features.

It has been found that there are specific points in the production process that require special control in order to obtain a product of the best possible quality and high health-promoting properties. The analysis of the management process using the Griffin's method is therefore multidimensional and can be used not only to analyse the process of managing organisations.

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