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Process of heat treatment and changes in garlic properties

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Abstract. This paper aims to present the results of research focused on the heat treatment of garlic (*Allium sativum*) into black garlic. The research compared three varieties of classic kitchen garlic (Dukat, Topaz and Sabagold), grown in the Czech Republic. The course of heat treatment in a hot air dryer was investigated at 60 °C. Changes in the weight and moisture of the samples were monitored gravimetrically for 78 days. The dry matter content was measured gravimetrically after drying at 105 °C. There were certain differences between the varieties studied. The intensive decrease in water content, dry basis u (g g^{-1}) during the first 20 days was the fastest in the Topaz variety, when it dropped below 0.4 (g g^{-1}) after only 9 days. In the Dukat and Sabagold variety water content, wet basis w (%), from the original values w = 62 to 66% dropped below 30% within 20 days, and in the Topaz variety below 20%. Changes in the colour of garlic cloves were measured by A CM-600d spectrophotometer. During the black garlic processing, its gradual darkening occurred. Lightness L* decreased in the Dukat variety from 80.39 to 27.47, Topaz from 78.29 to 29.09 and Sabagold from 83.64 to 28.72. In all varieties, colour changes occurred. Greenness (-a*) changed from the 9th day to a redness (a*) whose saturation gradually decreased. The yellowness (b*) of all varieties also decreased significantly.

Key words: CIELAB system, colour, garlic, heat treatment, Maillard reaction, moisture, spectrophotometer, temperature.

INTRODUCTION

Garlic (*Allium Sativum*) is a traditional vegetable that is widely used in cooking worldwide (Makarichiana et al., 2021; Qiu et al., 2022; Makarichiana et al., 2024; Park, et al., 2024). In addition to its interesting taste, its medicinal properties are also known (Zhang et al., 2021; Zerlasht, et al., 2024).

Another variant of garlic use, known for many centuries, is the heat treatment of garlic and the preparation of so-called black garlic (Turan & Şimşek 2022; Vathsala et al., 2023). The process of producing black garlic is based on the effect of higher temperature and humidity on garlic for a longer period of time. With this treatment, garlic loses its typical aroma (some people believe it is a smell) and pungent taste, and

its colour also changes from light to dark. These changes are caused by the Maillard reaction. The result is not only changes in physical properties, but also significant changes in chemical composition (Navrátilova, 2019; Turan & Şimşek 2022; Vathsala et al., 2023).

Compared to raw garlic, black garlic contains a greater number of substances with antioxidant effects, such as polyphenols, flavonoids and other organic compounds. These substances have proven medicinal effects, such as anti-inflammatory, antimicrobial, antidiabetic, hepatoprotective, neuroprotective, antitumor and others (Navrátilova, 2019; Turan & Şimşek 2022; Vathsala et al., 2023).

Various methods and procedures for processing black garlic at different temperatures have been tested for preparation e.g. (Sailah et al., 2024). The recommended temperature according to research results and analyses (Zhang et al., 2016) is below 70 °C.

Black garlic is prepared in a simpler home form by sealing it in containers and slowly baking it at higher temperatures, usually at 60 °C, for 3 to 4 weeks (Mikšík, 2015).

The aim of this article is to show the course of changes in the basic physical properties of garlic, i.e. moisture and colour, during its processing using the Maillard reaction by preparing black garlic using a traditional home method.

MATERIALS AND METHODS

For this research, fresh garlic was used a few days after harvest, grown in the Czech Republic. Three varieties of garlic were examined: Dukat, Topaz and Sabagold. The laboratory measurements were carried out at the Faculty of Engineering CULS Prague. The process of producing black garlic was based on traditional home preparation. After measuring the colour of the cloves, the fresh garlic bulbs were weighed (net weight), individually wrapped in aluminium foil and placed in measuring cups, the gross weight was weighed and placed in a Memmert laboratory heating and drying oven. The temperature in the oven was automatically maintained at 60 °C, while the ventilation was closed.

The samples were weighed every day during the entire measurement period of 78 days. Samples were weighed during the drying on the digital laboratory balance KERN-440-35N with a maximum load weight of 400 g, with resolution 0.01 g and accuracy ± 10 mg and values were recorded.

After the measurement of the black garlic production process was completed, the temperature in the oven was increased to 105 °C and after drying for 25 days until the weight stabilized, the dry matter of the samples was determined.

After the measurement of the black garlic production process was completed, the temperature in the oven was increased to 105 °C and drying at this temperature took place for 25 days until complete drying, i.e. until the weight stabilized, and thus the dry matter of the samples was determined.

During the production of black garlic, changes occur that are manifested by weight loss, just as during drying. Therefore, it is possible to follow the methodological procedure used in previous publications focused on drying agricultural materials, e.g. (Kic, 2018; Kic, 2019). The main parameters of garlic changes during the processing are calculated from the measured values of garlic samples. Water content, dry basis u is

defined as the ratio of the mass of water m_W contained in a solid to the mass of dry basis m_S, expressed in Eq. (1):

$$u = \frac{m_W}{m_S} \tag{1}$$

where u – water content, dry basis g g^{-1}; m_W – mass of water, g; m_S – mass of dry basis, g.

Water content, wet basis w is the ratio of the mass of water m_W contained in a solid to the mass of the moist solid $m = m_S + m_W$, expressed in Eq. (2):

$$w = \frac{m_W}{m} 100 \tag{2}$$

where w – water content, wet basis, %.

Changes of the water content du during the time difference dt describe the drying rate N expressed in Eq. (3):

$$N = \frac{\Delta u}{\Delta t} \tag{3}$$

where N – drying rate, g g^{-1}h^{-1}; t – time, h.

The colour of the cloves was measured at intervals of several days. The colour was evaluated according to the CIELAB system where colour attributes lightness (L* value), redness (a* value) and yellowness (b* value) were measured five times of each fresh sample and during the whole process of black garlic preparation at intervals of several days. The instrument used for this research, Spectrophotometer CM-600d Konica Minolta, was first calibrated. Calibration is based on the black (L* = 0) and white (L* = 100) standards.

The obtained results of the colour range coordinates of tested garlic samples were processed by Excel software and verified by statistical software Statistica 12 (*ANOVA* and *TUKEY HSD Test*) to determine whether the differences are significant at the significance level of 0.05.

RESULTS AND DISCUSSION

The kinetics of the black garlic preparation process described by the curves calculated according to equations (1), (2) and (3) are shown in Fig. 1–3.

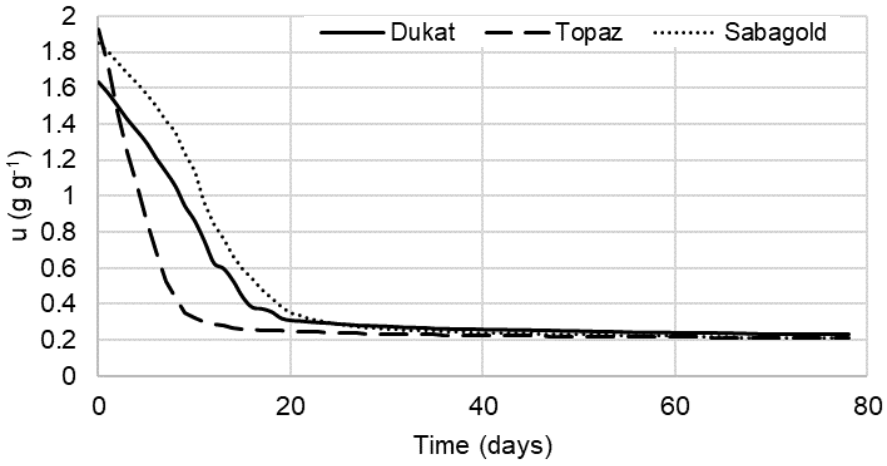

Figure 1. Water content, dry basis u (g g^{-1}) of garlic samples during the processing.

Fresh garlic processing into black garlic was uneven and certain differences existed between the investigated varieties. The intensive decrease of water content, dry basis u (g g^{-1}) during the first 20 days from values of 1.6 to 1.9 (g g^{-1}) to below 0.4 (g g^{-1}) was fastest in the Topaz variety, when it decreased below 0.4 (g g^{-1}) after only 9 days (Fig. 1).

These changes are also matched by changes in water content, wet basis w (%), the course of which is shown in Fig. 2. From the original values of w = 62 to 66%, within 20 days the water content, wet basis, dropped below 30%, and in the Topaz variety even below 20%.

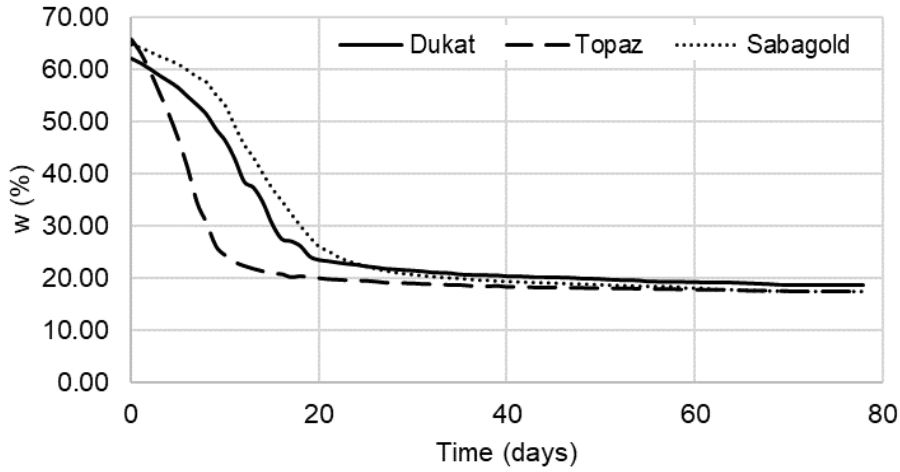

Figure 2. Water content, wet basis w (%) of garlic samples during the processing.

The drying rate (specific weight change due to water loss) of garlic N (g $g^{-1}h^{-1}$) is shown in Fig. 3. After 30 days, the N values (g $g^{-1}h^{-1}$) decreased significantly, therefore only this period is shown in Fig. 3. The highest N values were reached in the Topaz variety within the first 3 days. Overall, the N curves show that the first 30 days are the most important in terms of weight and moisture changes.

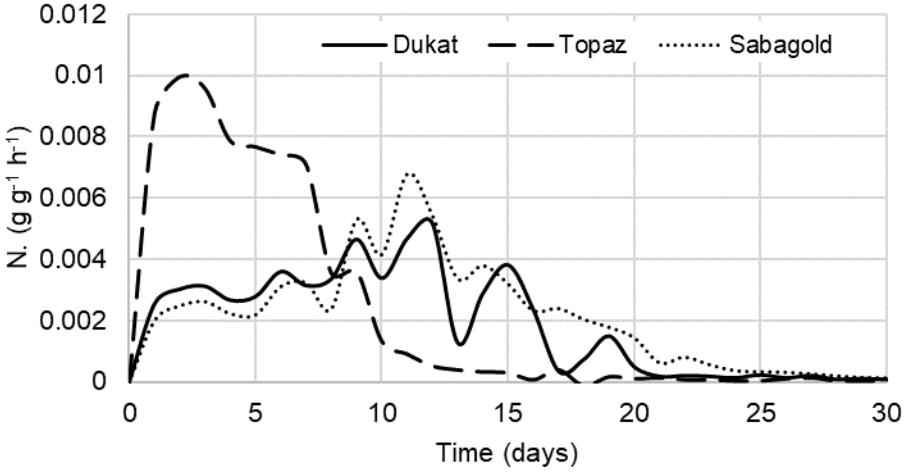

Figure 3. Drying rate N (g $g^{-1}h^{-1}$) of garlic samples during the first 30 days of processing.

The results of the lightness L* in Table 1 show that the measured samples of individual varieties of fresh garlic differ significantly. They also differ during processing into black garlic at 60 °C, only on the 54th day of processing were the differences in L* insignificant.

Tables 2 and 3 show the colour specifications a* and b*. Greenness (-a*) was found in all fresh garlic samples (Table 2). The most pronounced greenness was measured in the Sabagold variety (-2.63 ± 0.13). In the following days of processing, the influence of the Maillard reaction became apparent and all samples lost their greenness and turned into shades of redness, this shade was most intense on the 9th day in the Dukat variety (a* = 8.73 ± 0.13). On the 54th day of treatment, the differences in a* were insignificant. Yellowness (b*) was highest in the Dukat fresh garlic (22.12 ± 0.24), the Topaz and Sabagold varieties differed only insignificantly (Table 3). During the preparation of black garlic, differences in yellowness between the varieties alternated.

Tables 4–6 evaluate the results of lightness L* and colour specifications a* and b* throughout the entire measurement of the conversion of fresh garlic into black garlic for all varieties. A significant decrease in lightness, i.e. darkening, occurred on the 9th day for the Dukat varieties (ΔL* = 45.33) and Topaz (ΔL* = 48.06), while the Sabagold variety experienced a less pronounced darkening on the 9th day (ΔL* = 35.13). From the 26th to the 33rd day, a further significant

Table 1. Comparison of average values and standard deviation of the lightness L* of the investigated garlic varieties Dukat, Topaz and Sabagold on individual measured days

Day	Dukat	L*± SD Topaz	Sabagold
0	80.39 ± 0.08^{a}	78.29 ± 0.07^{b}	83.64 ± 0.17^{c}
9	35.06 ± 0.21^{a}	30.23 ± 0.25^{b}	48.51 ± 0.05^{c}
26	27.61 ± 0.19^{a}	28.52 ± 0.09^{a}	23.85 ± 1.48^{b}
33	29.80 ± 0.01^{a}	29.58 ± 0.04^{b}	26.09 ± 0.12^{c}
54	28.91 ± 1.18^{a}	28.68 ± 0.36^{a}	27.91 ± 1.79^{a}
78	27.47 ± 0.60^{a}	29.09 ± 0.45^{b}	28.72 ± 0.65^{b}

SD – standard deviation. $^{a, b, c}$ Identical superscript letters for numbers in a row indicate that there is no statistically significant difference between measured values.

Table 2. Comparison of average values and standard deviation of the colour shades, a* of the investigated garlic varieties Dukat, Topaz and Sabagold on individual measured days

Day	Dukat	a*± SD Topaz	Sabagold
0	-1.21 ± 0.05^{a}	-1.41 ± 0.01^{b}	-2.63 ± 0.13^{c}
9	8.73 ± 0.13^{a}	6.68 ± 0.51^{b}	6.63 ± 0.09^{b}
26	4.95 ± 0.44^{a,b}	6.52 ± 0.23^{a}	3.19 ± 2.62^{b}
33	5.38 ± 0.02^{a}	6.87 ± 0.09^{b}	6.46 ± 0.29^{c}
54	5.25 ± 2.03^{a}	5.35 ± 0.17^{a}	6.73 ± 0.35^{a}
78	2.13 ± 0.56^{a}	4.80 ± 0.50^{b}	3.96 ± 0.32^{b}

SD – standard deviation. $^{a, b, c}$ Identical superscript letters for numbers in a row indicate that there is no statistically significant difference between measured values.

Table 3. Comparison of average values and standard deviation of the colour shades, b* of the investigated garlic varieties Dukat, Topaz and Sabagold on individual measured days

Day	Dukat	b*± SD Topaz	Sabagold
0	22.12 ± 0.24^{a}	21.21 ± 0.10^{b}	21.30 ± 0.58^{b}
9	11.85 ± 0.27^{a}	7.70 ± 0.43^{b}	22.52 ± 0.16^{c}
26	5.22 ± 0.79^{a}	7.90 ± 0.14^{b}	3.16 ± 2.24^{a}
33	5.29 ± 0.03^{a}	7.51 ± 0.03^{b}	5.93 ± 0.21^{c}
54	4.90 ± 1.21^{a}	7.10 ± 0.06^{b}	7.20 ± 1.45^{b}
78	3.15 ± 0.35^{a}	6.39 ± 0.16^{b}	4.48 ± 1.34^{a}

SD – standard deviation. $^{a, b, c}$ Identical superscript letters for numbers in a row indicate that there is no statistically significant difference between measured values.

decrease in lightness occurred for Dukat (ΔL* = 7.45), Topaz (ΔL* = 1.71) and Sabagold (ΔL* = 24.66). Since this period, the lightness values L* have changed, and the measurement results have fluctuated alternately, which was influenced by small differences in the measured clove samples in the bulbs.

Greenness (-a*) changed from the 9th day to a redness (a*) whose saturation gradually decreased in Dukat (from a* = 8.73 to 2.13), Topaz (from a* = 6.68 to 4.80) and Sabagold (from a* = 6.63 to 3.96). Yellowness (b*) decreased from the 9th day, Dukat (from b* = 22.12 to 3.15), Topaz (from b* = 21.21 to 6.39) and Sabagold (from b* = 21.30 to 4.48). Also, the values of the colour specifications a* and b* showed occasional fluctuations in the measured values due to small differences in the measured clove samples in the bulbs.

Table 4. Colour range coordinates (L*, a* and b* mean values with SD) of tested garlic variety Dukat samples on individual measured days

Day	L*± SD	a*± SD	b*± SD
0	80.39 ± 0.08^{a}	-1.21 ± 0.05^{a}	22.12 ± 0.24^{a}
9	35.06 ± 0.21^{b}	8.73 ± 0.13^{b}	11.85 ± 0.27^{b}
26	27.61 ± 0.19^{c}	4.95 ± 0.44^{c}	5.22 ± 0.79^{c}
33	29.80 ± 0.01^{d}	5.38 ± 0.02^{c}	5.29 ± 0.03^{c}
54	28.91 ± 1.18^{d}	5.25 ± 2.03^{c}	4.90 ± 1.21^{c}
78	27.47 ± 0.60^{c}	2.13 ± 0.56^{d}	3.15 ± 0.35^{d}

SD – standard deviation. [a, b, c, d] Identical superscript letters for numbers in a column indicate that there is no statistically significant difference between measured values.

Table 5. Colour range coordinates (L*, a* and b* mean values with SD) of tested garlic variety Topaz samples on individual measured days

Day	L*± SD	a*± SD	b*± SD
0	78.29 ± 0.07^{a}	-1.41 ± 0.01^{a}	21.21 ± 0.10^{a}
9	30.23 ± 0.25^{b}	6.68 ± 0.51^{b}	7.70 ± 0.43^{b}
26	28.52 ± 0.09^{c}	6.52 ± 0.23^{b}	7.90 ± 0.14^{b}
33	29.58 ± 0.04^{d}	6.87 ± 0.09^{b}	$7.51 \pm 0.03^{b,c}$
54	28.68 ± 0.36^{c}	$5.35 \pm 0.17^{b,c}$	7.10 ± 0.06^{c}
78	$29.09 \pm 0.45^{c,d}$	4.80 ± 0.50^{c}	6.39 ± 0.16^{d}

SD – standard deviation. [a, b, c, d] Identical superscript letters for numbers in a column indicate that there is no statistically significant difference between measured values.

Table 6. Colour range coordinates (L*, a* and b* mean values with SD) of tested garlic variety Sabagold samples on individual measured days

Day	L*± SD	a*± SD	b*± SD
0	83.64 ± 0.17^{a}	-2.63 ± 0.13^{a}	21.30 ± 0.58^{a}
9	48.51 ± 0.05^{b}	$6.63 \pm 0.09^{b,c,d}$	22.52 ± 0.16^{a}
26	23.85 ± 1.48^{c}	$3.19 \pm 2.62^{b,d}$	3.16 ± 2.24^{b}
33	$26.09 \pm 0.12^{c,d}$	$6.46 \pm 0.29^{b,c,d}$	$5.93 \pm 0.21^{b,c}$
54	$27.91 \pm 1.79^{d,e}$	6.73 ± 0.35^{b}	7.20 ± 1.45^{c}
78	28.72 ± 0.65^{e}	$3.96 \pm 0.32^{b,c,d}$	$4.48 \pm 1.34^{b,c}$

SD – standard deviation. [a, b, c, d, e] Identical superscript letters for numbers in a column indicate that there is no statistically significant difference between measured values.

CONCLUSIONS

This article presents the results of research focused on the heat treatment of garlic (*Allium sativum*) and its transformation into black garlic. The results of measuring the heat process of garlic processing at a temperature of 60 °C showed that the decrease of water content, wet basis w (%), from the original values w = 62 to 66% to below 30% was within 20 days for the Dukat and Sabagold varieties, and below 20% for the Topaz variety.

The results of measuring the colour of garlic cloves showed that there are differences between the varieties in the initial lightness and during the darkening and colour change. To achieve the final dark colour in this process, 26 days were sufficient at a temperature of 60 °C.

Further research would be appropriate to focus on more detailed monitoring of the physical properties of garlic during the process of transformation of fresh garlic into

black garlic, especially over the course of 30 days, to verify the processing even at different temperatures and to expand the number of garlic varieties studied.

Experiments could also be focused on using different methods of sealing garlic to prepare black garlic in different containers or other packaging.

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