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Nutraceutical stability in *Lentinus squarrosulus* after drying and frying for snack production

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Abstract---Pathogenesis of neurological diseases is associated with free-radical-mediated inflammatory processes. Phenolic compounds, saponin, and γ -aminobutyric acid (GABA) are nutraceuticals with neuroprotective properties. *Lentinus squarrosulus* is a mushroom with high proteins low calories, and nutraceuticals. This research aimed to investigate the nutraceutical contents of total phenolic compounds, saponins, γ -aminobutyric acid (GABA), and antioxidant activity in this mushroom after drying and frying for snack production. The

nutraceutical contents and antioxidant activity were measured by Folin–Ciocalteu method and 2,2-diphenylpicrylhydrazyl (DPPH) assay, respectively. The stability of these nutraceuticals was also determined after drying and deep frying mushrooms in preparation for snack production. Results showed that the mushrooms after drying at 50 and 60 °C until the moisture content was below 12 % (according to Thai Community Products Standard) had water activity (aW) of 0.52 to 0.59. The dried mushrooms had lower lightness, redness, and yellowness with the increased drying temperature ($p \leq 0.05$). The total phenolic content of dried mushrooms was not significantly different from that of fresh mushrooms, but saponin, GABA, and antioxidant activity were higher than in the fresh samples. The samples dried at 60 °C had the highest content of saponin (15 mg/g), GABA (1.45 mg/g), and the highest antioxidant activity compared to the other samples (IC_{50} 0.66 mg/g) ($p \leq 0.05$). Subsequently, the mushroom dried at 60 °C was chosen for frying at 160 and 170 °C for 2 min and found no difference in aW (0.46–0.48). The fried mushrooms' lightness, redness, and yellowness significantly decreased with the increased frying temperature. In addition, it was found that the mushrooms fried at 170 °C had higher phenolic compounds than those fried at 160 °C, while the GABA, saponin, and antioxidant activity decreased with the increased frying temperature ($p \leq 0.05$). In conclusion, drying and frying preserved GABA and saponin contents, but not antioxidant activity. The lower temperature of food processing should be considered.

Keywords---*Lentinus squarrosulus*, neurodegeneration, γ -aminobutyric acid, saponin, antioxidant.

Introduction

A non-proteinogenic amino acid neurotransmitter γ -aminobutyric acid (GABA) plays a pivotal role in the regulation of normal neurological functions (Allen et al., 2021). GABA is produced by L-glutamic acid by an enzymatic activity of glutamic acid decarboxylase (Martin & Olsen, 2000). Dysfunctions of GABA and the GABA receptor system are linked to abnormal glutamatergic pyramidal and cortical activities (Jahangir et al., 2021). Due to its plethora of functions, the GABA signaling system dysfunction is associated with neurological diseases including schizophrenia, Alzheimer's disease, and Parkinson's disease (Błaszczuk, 2016; Egerton et al., 2017; Kwakowsky et al., 2018). The etiology of these neurological diseases is associated with free-radical-mediated inflammatory processes (Nikam et al., 2009; Wojtunik-Kulesza et al., 2016; Wu et al., 2013). The mitochondrial-derived reactive oxygen species (mROS) has been reported to regulate the postsynaptic GABA receptor activity in neural cells (Accardi et al., 2014).

Several plant-derived products have been found to contain GABA and exhibit neuroprotective effects. GABA produced by *Lactobacillus buchneri* in fermented cabbage (Kimchi) had a neuroprotective effect against neurotoxic-induced neural cell death (Cho et al., 2007). GABA was also present in *Lactobacillus brevis*-

fermented soybean (Jang et al., 2015). In unprocessed parts of plants, GABA was found in potatoes, soybeans, oats, rice, wheat, and barley (Li et al., 2021). Mushrooms are consumed worldwide as food and nutraceuticals. The consumable mushrooms have been recognized as a part of modern medicinal plants in preventing and treating various diseases (Kidd, 2000). So far, many edible mushrooms have been found to be rich sources of nutraceuticals and possess antibacterial, antiviral, and antioxidant activities (Garcia-Lafuente et al., 2010; Ribeiro et al., 2007; Schillaci et al., 2013). Some species of mushrooms are reportedly more nutritive than vegetables. Twenty-two species of mushrooms are cultivable including *Lentinus squarrosulus* (De Leon et al., 2017).

Lentinus squarrosulus belongs to the family Polyporaceae grown in tropical countries like Thailand. It is a source of proteins and nutraceuticals such as amino acids, phenolic compounds, and glycosides; it thus has been found widely consumed in households as well as processed in the food industry (Ghate & Sridhar, 2017). Nine essential and nine non-essential amino acids have been identified in this mushroom (Oni et al.). In addition, GABA has been also identified in various types of mushrooms (Yuwa-amornpitaK et al., 2020). However, whether GABA is present in the *Lentinus squarrosulus* has been still elusive. Besides, phenolic compounds are nutraceuticals that exist in various types of mushrooms. So far, at least twenty-eight phenolic compounds have been identified in the mushrooms (Kim et al., 2008). An antioxidant of the dried and fried *Lentinus squarrosulus* has also not been investigated.

Saponin is one of the naturally occurring glycosides that are widely present in plants during their growth and development (Moses et al., 2014). Saponin is a glycoside of triterpenoid with a wide range of nutraceutical activities such as antimicrobial, analgesic, antitumor, anti-inflammatory, and antioxidant activities (Hassan et al., 2012; Sun et al., 2015). The stability of the nutraceutical activities in mushrooms can be modified by post-harvest heating processes such as drying and frying (Roncero-Ramos et al., 2017). Even though saponin has been identified in *Lentinus squarrosulus*, its antioxidant activities in dried and fried forms have not been examined. Therefore, this present study aimed to investigate the nutraceutical contents of total phenolic compounds, GABA, saponin, and antioxidant activity in *Lentinus squarrosulus* prepared for snack production.

Materials and Methods

Mushroom sample preparation and extraction

The *Lentinus squarrosulus* mushroom samples were weighted and cleaned. The 50 g of mushroom samples were extracted by immersion in 100 mL ethanol for 24 h. Then the samples were filtered. The extraction and filtration were repeated twice to obtain a final volume of 200 mL of liquid samples for further analysis.

Moisture content and water activity measurement

The moisture content of the mushroom sample (1 g) was measured with a moisture analyzer (model MB23, Ohaus), which displayed the results on the LCD screen. Water activity was measured with the water activity meter model WA-60A.

Each sample was measured for 5 min. All measurements were performed in triplicates.

Color measurements

The mushrooms' lightness (L^*), red/green coordinate (a^*), and yellow/blue coordinate (b^*) values were evaluated with a colorimeter (Minolta CR 400, Minolta GmbH, Langenhagen, Germany). It is a three dimensional Cartesian space with three mutually perpendicular color coordinates: L^* , the correlate of perceptual lightness; a^* that represents the red ($a^* > 0$) green ($a^* < 0$) axis and b^* that represents the yellow ($b^* > 0$) blue ($b^* < 0$) axis (Hernandez et al., 2016).

Saponin content measurement

The total saponin content measurement method was adapted from the method of Hiai and co-workers (Hiai et al., 1975). Aescin, a component of triterpenoid saponins at a concentration of 0.93-15 g/l was used for standard curve plotting. Saponin content was measured by adding 0.5 ml 8% vanillin and 5 ml sulfuric acid into a 0.5 ml sample solution, incubated at 60 °C for 15 min. The samples were cooled down in a room-temperature water bath. The absorbance of the mixture was measured at 560 nm using a UV-Vis spectrophotometer. All measurements were performed in triplicates. The results were expressed as mg of aescin equivalent/100 g dry weight.

GABA measurement

The standard solution of GABA was prepared with concentrations of 250-2,000 µg/ml from GABA stock solution (Sigma, St. Louis, USA). One hundred µl of each gradient was added to a test tube, followed by 200 µl and 1 ml 6% phenol reagent. All were mixed well and incubated in the cold-water bath. Four hundred µl 7.5% sodium hypochlorite reagent was added, mixed well, cooled, and heated in the water bath for 10 min. The standard samples were then immediately cooled down for 5 min. The mushroom samples were extracted with 30 ml 70% ethanol, and centrifuged twice at 8,000 g at 4 °C for 5 min. The supernatants were collected and dried at 40 °C to obtain 3 ml extracted samples. The samples were aliquoted for 100 µl, added 200 µl borate buffer (200 mM boric acid and 200 mM sodium borate, pH 9) and the 1 ml 6% phenolic agent. All were mixed well and supplemented with 400 µl 7.5% sodium hypochlorite reagent, cooled, and heated in the water bath for 10 min. The mushroom samples were then immediately cooled down for 5 min. All the samples were measured at 630 nm using a UV-Vis spectrophotometer. The standard curve was plotted between concentrations (x-axis) and absorbance (y-axis).

Total phenolic content measurements

The total phenolic contents of the mushroom extract were measured by the Folin-Ciocalteu's method. For standard curve plotting, gallic acid was prepared in different concentrations as standard samples (0-50 mg/ml), and a calibration curve was created. The 400 µl of the gallic acid standard solution was added to 2 ml Folin-Ciocalteu reagent, mixed well, and incubated at room temperature for 5

min. Subsequently, 1.6 ml of 7.5% sodium carbonate was added and incubated at room temperature for 30 min. The absorbance of the mixture was measured at 765 nm using a UV-Vis spectrophotometer and used for the standard curve plotting. Total phenolic contents were measured from a 400 μ l sample solution in the same method as the standard solution. All measurements were performed in triplicates. The concentration of total phenolic contents in the samples was calculated according to the regression equation of the standard curve. The results were expressed as mg of gallic acid equivalent/100 g dry weight.

DPPH measurements

Antioxidant activity of mushroom extracts was performed by using a 2,2-diphenylpicrylhydrazyl (DPPH) assay (Bakir et al., 2018). Methanol solution of DPPH radical was purple and had absorbance ranging between 515–517 nm. When the antioxidant concentration increases, the color of the DPPH radical becomes lighter. Therefore, the antioxidant concentration could be measured by a spectrophotometer. Trolox at a concentration of 31.25–500 mM was used as a standard solution. The 2 ml 0.1 mM DPPH solution was added to each concentration of Trolox, and kept in the darkroom for 30 min. The absorbance at 517 nm was measured with the UV-Vis spectrophotometer correspondingly to the blank. The amount of antioxidant required to reduce DPPH concentration by 50% is called IC₅₀ (mg/ml) (Frankel & Meyer, 2000). The percentage of radical scavenging activity is calculated by the following formula:

$$\% \text{ inhibition} = [(C0 - C1)/C0] \times 100$$

C0 = concentration of control solution (no antioxidant added) and C1 = concentrations of sample solutions (when antioxidant was present) (Huang et al., 2005). The IC₅₀ value was determined from the graph slope “y = mx + c” formula obtained from the graph for standard Trolox and mushroom extracts (Mukherjee et al., 2011).

Statistical analysis

The data are expressed as mean \pm SD. Different alphabets indicate significant differences between the groups in the same column (p < 0.05). The normality of sample data was tested by the Kolmogorov-Smirnov test. Multiple comparisons were performed using One-way ANOVA and Duncan’s new multiple range test post hoc test. The level of statistical significance was p < 0.05. All data were analyzed by SPSS version 18.0.

Results

We first investigated physical properties of fresh and dried *Lentinus squarrosulus* mushroom samples. *Lentinus squarrosulus* mushroom samples were dried at 50 and 60 °C until they had < 12% moisture content and aW < 0.6. Under these conditions, the samples were free of microorganisms (Table 1). Subsequently, color coordinates of lightness (L*), red/green coordinate (a*), and yellow/blue coordinate (b*) values of the samples were measured. Results showed that drying at 50 °C had no effects, but drying at 60 °C significantly reduced the lightness,

redness, and yellowness of the samples (Table 2). Next, phenolic compound contents and antioxidant activity in fresh and dried *Lentinus squarrosulus* mushroom samples were measured. The samples were analyzed for total phenolic contents. It was shown that drying the samples either at 50 or 60 °C did not change the total phenolic contents (Table 3). However, drying significantly increased phenolic compound contents – saponin (from 1.73±1.16 mg/g in the fresh samples to 11.42±0.61 and 15.00±0.55 mg/g in 50 and 60 °C dried mushroom samples, respectively) and GABA (from 1.19±0.14 mg in the fresh samples to 1.45±0.09 mg/g in 60 °C dried mushroom samples) (Table 4). Consequently, the DPPH assay revealed that increased antioxidant activity in both 50 and 60 °C dried mushroom samples as signified by reduced IC₅₀ from 1.07±0.13 in the fresh samples to 0.86±0.02 and 0.66±0.01 in 50 and 60 °C dried mushroom samples, respectively (Table 5). Physical properties of fried *Lentinus squarrosulus* mushroom samples were then examined. The dried samples were fried at 160 and 170 °C; and measured for moisture content and a_w. Results showed that moisture content was reduced to 4.34±0.28 and 4.32±0.16 %, respectively. Meanwhile, a_w also significantly reduced to 0.48±0.01 and 0.48±0.01, respectively (Table 6). Color coordinates of L*, a*, and b* values of the samples fried at 160 °C had no effects, but frying at 170 °C significantly reduced the lightness, redness, and yellowness of the samples (Table 7). Phenolic compound contents and antioxidant activity in fried *Lentinus squarrosulus* mushroom samples were also measured. Results showed that frying the samples at 160 or 170 °C significantly increased total phenolic contents in comparison to fresh and dried samples (Table 8). Moreover, phenolic compound contents also significantly increased– saponin (from 1.73±1.16 mg/g in the fresh samples to 7.70±2.88 and 5.43±3.48 mg/g in 160 and 170 °C fried mushroom samples, respectively). However, GABA increased from 1.19±0.14 in the fresh samples to 1.23±0.14 mg/g in 160 °C fried mushroom samples but reduced to 1.08±0.20 in 170 °C fried samples (Table 9). The DPPH assay showed a reduction of antioxidant activity in both 160 and 170 °C fried mushroom samples as signified by increments of IC₅₀ from 1.07±0.13 in the fresh samples to 4.97±0.72 and 6.67±0.63 in 160 and 170 °C fried mushroom samples, respectively (Table 10).

Table 1 Moisture content and water activity in fresh and dried *Lentinus squarrosulus* mushroom samples

Mushroom sample	Moisture content (%)	Water activity (a _w)
Fresh	87.69±0.79 ^a	0.92±0.01 ^a
Dried at 50 °C	9.69±0.07 ^b	0.59±0.02 ^b
Dried at 60 °C	9.70±0.18 ^b	0.59±0.01 ^b

Table 2. CIELAB color coordinates of lightness (L*), red/green coordinate (a*), and yellow/blue coordinate (b*) values of fresh, dried at 50 °C, and dried at 60 °C *Lentinus squarrosulus* mushroom.

Mushroom sample	Color value		
	L*	a*	b*




Fresh		30.21 ± 1.37^a	6.91 ± 1.05^a	10.29 ± 4.35^{ab}
Dried at 50 °C		27.48 ± 0.23^a	6.72 ± 0.14^a	10.28 ± 0.01^{ab}
Dried at 60 °C		24.83 ± 2.55^b	4.15 ± 0.74^b	6.73 ± 0.38^b

Table 3 Total phenolic contents in fresh, dried at 50 °C, and dried at 60 °C *Lentinus squarrosulus* mushroom

Mushroom sample	Total phenolic content (mg gallic acid/g)
Fresh	6.69 ± 0.72^a
Dried at 50 °C	6.73 ± 0.90^a
Dried at 60 °C	6.75 ± 0.68^a

Table 4 Saponin and GABA contents in fresh, dried at 50 °C, and dried at 60 °C *Lentinus squarrosulus* mushroom

Mushroom sample	Saponin content (mg/g)	GABA content (mg/g)
Fresh	1.73 ± 1.16^c	1.19 ± 0.14^b
Dried at 50 °C	11.42 ± 0.61^b	1.22 ± 0.13^{ab}
Dried at 60 °C	15.00 ± 0.55^a	1.45 ± 0.09^a

Table 5 Antioxidant activity in fresh, dried at 50 °C, and dried at 60 °C *Lentinus squarrosulus* mushroom

Mushroom sample	IC ₅₀ (mg/g)
Trolox standard	0.18±0.02 ^a
Fresh	1.07±0.13 ^d
Dried at 50 °C	0.86±0.02 ^c
Dried at 60 °C	0.66±0.01 ^b

Table 6 Moisture content and water activity in fresh, dried at 60 °C, fried at 160 °C, and fried at 170 °C *Lentinus squarrosulus* Mont. Mushroom

Mushroom sample	Moisture content (%)	Water activity (a _w)
Fresh	87.69±0.79 ^a	0.92±0.01 ^a
Dried at 60 °C	9.70±0.18 ^b	0.59±0.01 ^b
Fried at 160 °C	4.34±0.28 ^c	0.48±0.01 ^c
Fried at 170 °C	4.32±0.16 ^c	0.48±0.01 ^c

Table 7 CIELAB color coordinates of lightness (L*), red/green coordinate (a*), and yellow/blue coordinate (b*) values of fresh, dried at 60 °C, fried at 160 °C, and fried at 170 °C *Lentinus squarrosulus* mushroom

Mushroom sample	Color value		
	L*	a*	b*
Fresh	30.21±1.37 ^a	6.91±1.05 ^a	10.29±4.35 ^{ab}
Dried at 60 °C	24.83±2.55 ^b	4.15±0.74 ^b	6.73±0.38 ^b
Fried at 160 °C	27.28±0.57 ^{ab}	6.91±1.05 ^a	10.30±4.35 ^a
Fried at 170 °C	17.86±2.70 ^c	4.15±0.74 ^a	6.72±0.40 ^c

Table 8 Total phenolic contents in fresh, dried at 60 °C, fried at 160 °C, and fried at 170 °C *Lentinus squarrosulus* mushroom

Mushroom sample	Total phenolic content (mg gallic acid/g)
Fresh	6.69±0.68 ^c
Dried at 60 °C	6.75±0.72 ^c
Fried at 160 °C	6.96±0.42 ^b
Fried at 170 °C	7.31±0.63 ^a

Table 9 Saponin and GABA contents in fresh, dried at 60 °C, fried at 160 °C, and fried at 170 °C *Lentinus squarrosulus* mushroom

Mushroom sample	Saponin content (mg/g)	GABA content (mg/g)
Fresh	1.73±1.16 ^c	1.19±0.14 ^b
Dried at 60 °C	15.00±0.55 ^a	1.45±0.90 ^a
Fried at 160 °C	7.70±2.88 ^a	1.23±0.14 ^{ab}
Fried at 170 °C	5.43±3.48 ^{ab}	1.08±0.20 ^b

Table 10 Antioxidant activity in fresh, dried at 60 °C, fried at 160 °C, and fried at 170 °C *Lentinus squarrosulus* mushroom

Mushroom sample	IC ₅₀ (mg/g)
Trolox standard	0.18±0.02 ^a
Fresh	1.07±0.13 ^d
Dried at 60 °C	0.66±0.01 ^b
Fried at 160 °C	4.97±0.72 ^c
Fried at 170 °C	6.67±0.63 ^d

Discussion

Lentinus squarrosulus mushroom contains various types of nutraceuticals including phenolic compounds, flavonoids, lectins, antifungal proteins, and immunostimulatory glucans (Lau & Abdullah, 2017). This present study showed that nutraceutical stability of the mushroom was able to be modified by drying and frying. Our main findings were 1) drying reduced lightness, redness, and yellowness increased phenolic compound contents (saponin and GABA), and increased antioxidant activity of the mushroom; and 2) frying reduced lightness, redness, and yellowness, increased phenolic compound contents (saponin and GABA), and decreased antioxidant activity of the mushroom.

GABA has been previously found in 17 types of mushrooms in the local forest in Thailand (Yuwa-amornpitaK et al., 2020). Bioactive compounds in *Lentinus squarrosulus* mushroom have been extracted and used against pathological conditions such as gastric ulcer, anemia, cough, and fever (Ugbogu et al., 2019). These compounds included minerals (calcium, iron, magnesium, phosphorous, and potassium), vitamins (ascorbic acid, folic acid, riboflavin, and thiamine), phenolic compounds (alkaloids, anthraquinones, catechin, flavonoids, gallic acid, isoquercetin, kaempferol, quinolones, saponins, tannins, and terpenes), and amino acids (Ugbogu et al., 2019). However, to our knowledge, this present study was the first to identify GABA in *Lentinus squarrosulus* mushroom. Moreover, GABA content was preserved upon the heating process by drying and frying. This finding indicates that GABA is very stable under these circumstances. In the food industry, thermal processing is important for food preservation by inactivating pathogens and microorganisms (Maskan, 2006). In general, five methods of drying methods are used i.e., convective, vacuum, microwave, freezing, and osmotic drying (Krokida et al., 2001). Among these, the microwave is the most effective method to preserve total phenolic contents and natural colors of the samples (Zielinska & Zielinska, 2019). Changes in the colors of fruits and vegetables can be attributed to non-enzymatic browning and thermal destruction of pigments like carotenoids and chlorophyll (Maskan, 2006). The color deterioration has been investigated in several types of fruits like bananas and apples (Maskan, 2000; Rocha & Morais, 2003). It has been previously shown that the convective heat at 55 °C also reduced the tristimulus colors of the oyster mushroom (*Pleurotus ostreatus*) (Rocha & Morais, 2003). In the present study, the fresh mushroom samples were originally white. Then tristimulus colors were changed by the heat of convective drying and further altered by frying.

Phenolic compound saponin extracted from the medicinal plant *Conyza blini* has been reported to have protective activity on gastric mucosa with its anti-lipid peroxidation and free radical clearance characteristics (Ma & Liu, 2014). The phenolic saponin has a neuroprotective effect on alleviating free radical-mediated central nervous system diseases such as Alzheimer's disease, Parkinson's disease, and stroke (Sun et al., 2015). Anti-inflammatory property of saponin extracted from the leaves and roots of *Camellia sinensis* has been shown to inhibit carrageenan-induced inflammation. Even though the present study showed that the saponin contents were upregulated by drying and frying, further study should be performed to evaluate the effects of *Lentinus squarrosulus*-extract *in vivo*. Interestingly, drying *Lentinus edodes* gave rise to low oil uptake on frying (decreased up to 22 %) (Ghate & Sridhar, 2017). Therefore, frying *Lentinus squarrosulus* might be one of the healthier food alternatives. However, this present study showed that frying significantly reduced the antioxidant activity of the mushroom. This finding indicates that other bioactive compounds might be also destroyed by heating processes. To overcome this limitation of food processing, other heat process methods should be introduced to preserve the antioxidant characteristics.

Conclusion

In conclusion, our present study demonstrates that drying at 50 and 60 °C and frying 160 and 170 °C were able to preserve GABA and saponin contents. However, the antioxidant activity was lower with the increasing temperature of frying. Therefore, lower temperatures of food processing should be considered to preserve other nutraceuticals. Further study with other optimized conditions should be further carried out.

Conflict of Interest

The authors have no conflicts of interest to declare.

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References

- Accardi, M. V., Daniels, B. A., Brown, P. M., Fritschy, J. M., Tyagarajan, S. K., & Bowie, D. (2014). Mitochondrial reactive oxygen species regulate the strength of inhibitory GABA-mediated synaptic transmission. *Nat Commun*, 5, 3168. <https://doi.org/10.1038/ncomms4168>
- Allen, M. J., Sabir, S., & Sharma, S. (2021). GABA Receptor. StatPearls Publishing, Treasure Island (FL). <http://europepmc.org/abstract/MED/30252380>
- Bakir, T., Karadeniz, M., & Unal, S. (2018). Investigation of antioxidant activities of *Pleurotus ostreatus* stored at different temperatures. *Food science & nutrition*, 6(4), 1040-1044.

- Blaszczyk, J. W. (2016). Parkinson's Disease and Neurodegeneration: GABA-Collapse Hypothesis. *Front Neurosci*, 10, 269. <https://doi.org/10.3389/fnins.2016.00269>
- Cho, Y. R., Chang, J. Y., & Chang, H. C. (2007). Production of gamma-aminobutyric acid (GABA) by *Lactobacillus buchneri* isolated from kimchi and its neuroprotective effect on neuronal cells. *J Microbiol Biotechnol*, 17(1), 104-109. <https://www.ncbi.nlm.nih.gov/pubmed/18051360>
- De Leon, A., Guinto, L., De Ramos, P., & Kalaw, S. (2017). Enriched cultivation of *Lentinus squarrosulus* (Mont.) Singer: A newly domesticated wild edible mushroom in the Philippines. *Mycosphere*, 8(3), 615-629.
- Egerton, A., Modinos, G., Ferrera, D., & McGuire, P. (2017). Neuroimaging studies of GABA in schizophrenia: a systematic review with meta-analysis. *Transl Psychiatry*, 7(6), e1147. <https://doi.org/10.1038/tp.2017.124>
- Frankel, E. N., & Meyer, A. S. (2000). The problems of using one-dimensional methods to evaluate multifunctional food and biological antioxidants. *Journal of the Science of Food and Agriculture*, 80(13), 1925-1941.
- Garcia-Lafuentea, A., Moro, C., Villares, A., Guillamon, E., A Rostagno, M., D'Arrigo, M., & Alfredo Martinez, J. (2010). Mushrooms as a source of anti-inflammatory agents. *Anti-Inflammatory & Anti-Allergy Agents in Medicinal Chemistry (Formerly Current Medicinal Chemistry-Anti-Inflammatory and Anti-Allergy Agents)*, 9(2), 125-141.
- Ghate, S. D., & Sridhar, K. R. (2017). Bioactive potential of *Lentinus squarrosulus* and *Termitomyces clypeatus* from the southwestern region of India.
- Hassan, H. S., Sule, M. I., Musa, A. M., Musa, K. Y., Abubakar, M. S., & Hassan, A. S. (2012). Anti-inflammatory activity of crude saponin extracts from five Nigerian medicinal plants. *Afr J Tradit Complement Altern Med*, 9(2), 250-255. <https://doi.org/10.4314/ajtcam.v9i2.10>
- Hernandez, B., Saenz, C., Alberdi, C., & Dineiro, J. M. (2016). CIELAB color coordinates versus relative proportions of myoglobin redox forms in the description of fresh meat appearance. *J Food Sci Technol*, 53(12), 4159-4167. <https://doi.org/10.1007/s13197-016-2394-6>
- Hiai, S., Oura, H., Odaka, Y., & Nakajima, T. (1975). A colorimetric estimation of ginseng saponins. *Planta Medica*, 28(08), 363-369. <http://europepmc.org/books/NBK526124> <https://www.ncbi.nlm.nih.gov/books/NBK526124>
- Huang, D., Ou, B., & Prior, R. L. (2005). The chemistry behind antioxidant capacity assays. *Journal of agricultural and food chemistry*, 53(6), 1841-1856.
- Jahangir, M., Zhou, J.-S., Lang, B., & Wang, X.-P. (2021). GABAergic System Dysfunction and Challenges in Schizophrenia Research. *Frontiers in cell and developmental biology*, 9, 663854.
- Jang, E. K., Kim, N. Y., Ahn, H. J., & Ji, G. E. (2015). gamma-Aminobutyric Acid (GABA) Production and Angiotensin-I Converting Enzyme (ACE) Inhibitory Activity of Fermented Soybean Containing Sea Tangle by the Co-Culture of *Lactobacillus brevis* with *Aspergillus oryzae*. *J Microbiol Biotechnol*, 25(8), 1315-1320. <https://doi.org/10.4014/jmb.1412.12038>
- Kidd, P. M. (2000). The use of mushroom glucans and proteoglycans in cancer treatment. *Altern Med Rev*, 5(1), 4-27. <https://www.ncbi.nlm.nih.gov/pubmed/10696116>
- Kim, M. Y., Seguin, P., Ahn, J. K., Kim, J. J., Chun, S. C., Kim, E. H., Seo, S. H., Kang, E. Y., Kim, S. L., Park, Y. J., Ro, H. M., & Chung, I. M. (2008). Phenolic

- compound concentration and antioxidant activities of edible and medicinal mushrooms from Korea. *J Agric Food Chem*, 56(16), 7265-7270. <https://doi.org/10.1021/jf8008553>
- Krokida, M. K., Maroulis, Z. B., & Saravacos, G. D. (2001). The effect of the method of drying on the colour of dehydrated products. *International journal of food science & technology*, 36(1), 53-59.
- Kwakowsky, A., Calvo-Flores Guzman, B., Govindpani, K., Waldvogel, H. J., & Faull, R. L. (2018). Gamma-aminobutyric acid A receptors in Alzheimer's disease: highly localized remodeling of a complex and diverse signaling pathway. *Neural Regen Res*, 13(8), 1362-1363. <https://doi.org/10.4103/1673-5374.235240>
- Lau, B. F., & Abdullah, N. (2017). Bioprospecting of *Lentinus squarrosulus* Mont., an underutilized wild edible mushroom, as a potential source of functional ingredients: a review. *Trends in Food Science & Technology*, 61, 116-131.
- Li, L., Dou, N., Zhang, H., & Wu, C. (2021). The versatile GABA in plants. *Plant Signal Behav*, 16(3), 1862565. <https://doi.org/10.1080/15592324.2020.1862565>
- Ma, L., & Liu, J. (2014). The protective activity of *Conyza blinii* saponin against acute gastric ulcer induced by ethanol. *J Ethnopharmacol*, 158 Pt A, 358-363. <https://doi.org/10.1016/j.jep.2014.10.052>
- Martin, D. L., & Olsen, R. W. (2000). GABA in the nervous system: the view at fifty years. Lippincott Williams and Wilkins.
- Maskan, M. (2000). Microwave/air and microwave finish drying of banana. *Journal of food engineering*, 44(2), 71-78.
- Maskan, M. (2006). Effect of thermal processing on tristimulus colour changes of fruits. *Stewart Postharvest Review*, 5(10).
- Moses, T., Papadopoulou, K. K., & Osbourn, A. (2014). Metabolic and functional diversity of saponins, biosynthetic intermediates and semi-synthetic derivatives. *Crit Rev Biochem Mol Biol*, 49(6), 439-462. <https://doi.org/10.3109/10409238.2014.953628>
- Mukherjee, S., Pawar, N., Kulkarni, O., Nagarkar, B., Thopte, S., Bhujbal, A., & Pawar, P. (2011). Evaluation of free-radical quenching properties of standard Ayurvedic formulation Vayasthapana Rasayana. *BMC complementary and alternative medicine*, 11(1), 1-6.
- Nikam, S., Nikam, P., & Ahaley, S. (2009). Role of free radical and antioxidant imbalance in pathogenesis of Parkinson's disease. *Biomedical Research*, 20(1), 55-58.
- Normatova, S. A. ., Botirov, M. T. ., Ruzmatova, K. K. ., & Mamarasulov, J. O. ugli . (2021). Hygienic basis for contamination of food products and production of dairy products until 2030. *International Journal of Health & Medical Sciences*, 4(1), 123-128. <https://doi.org/10.31295/ijhms.v4n1.1592>
- Oni, J. O., Basse, G. A., Agba, M.-I. O., & Markson, A.-A. A. Amino Acids Composition of Some Wild Edible Mushrooms from Southern Cross River State, Nigeria. *Amino acids*, 14, 15.
- Ribeiro, B., Valentão, P., Baptista, P., Seabra, R. M., & Andrade, P. B. (2007). Phenolic compounds, organic acids profiles and antioxidative properties of beefsteak fungus (*Fistulina hepatica*). *Food and Chemical Toxicology*, 45(10), 1805-1813.
- Rocha, A., & Morais, A. (2003). Shelf life of minimally processed apple (cv. Jonagored) determined by colour changes. *Food control*, 14(1), 13-20.

- Roncero-Ramos, I., Mendiola-Lanao, M., Pérez-Clavijo, M., & Delgado-Andrade, C. (2017). Effect of different cooking methods on nutritional value and antioxidant activity of cultivated mushrooms. *International Journal of Food Sciences and Nutrition*, 68(3), 287-297.
- Schillaci, D., Arizza, V., Gargano, M. L., & Venturella, G. (2013). Antibacterial activity of mediterranean oyster mushrooms, species of genus *Pleurotus* (higher basidiomycetes). *International journal of medicinal mushrooms*, 15(6).
- Sun, A., Xu, X., Lin, J., Cui, X., & Xu, R. (2015). Neuroprotection by saponins. *Phytother Res*, 29(2), 187-200. <https://doi.org/10.1002/ptr.5246>
- Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2021). Health and treatment of diabetes mellitus. *International Journal of Health Sciences*, 5(1), i-v. <https://doi.org/10.53730/ijhs.v5n1.2864>
- Ugbogu, E. A., Akubugwo, I. E., Ude, V. C., Gilbert, J., & Ekeanyanwu, B. (2019). Toxicological evaluation of phytochemical characterized aqueous extract of wild dried *Lentinus squarrosulus* (Mont.) mushroom in rats. *Toxicological research*, 35(2), 181-190.
- Wojtunik-Kulesza, K. A., Oniszczyk, A., Oniszczyk, T., & Waksmundzka-Hajnos, M. (2016). The influence of common free radicals and antioxidants on development of Alzheimer's Disease. *Biomedicine & pharmacotherapy*, 78, 39-49.
- Wu, J. Q., Kosten, T. R., & Zhang, X. Y. (2013). Free radicals, antioxidant defense systems, and schizophrenia. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, 46, 200-206.
- Yuwa-amornpitaK, T., Butkhup, L., & Yeunyaw, P.-N. (2020). Amino acids and antioxidant activities of extracts from wild edible mushrooms from a community forest in the Nasrinual District, Maha Sarakham, Thailand. *Food Science and Technology*, 40, 712-720.
- Zielinska, M., & Zielinska, D. (2019). Effects of freezing, convective and microwave-vacuum drying on the content of bioactive compounds and color of cranberries. *LWT*, 104, 202-209.