Grape Pomace for Tofu Production

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Tofu, soybean curd, or bean curd is one of the most important soya products and is produced by the addition of coagulants (acids, salts or enzymes) to soymilk. It is widely consumed in Asia and has been growing in popularity worldwide because of its high nutritional value, good texture, and unique flavour. It has high contents of highly digestible proteins, dietary fibre, soy saponins, and isoflavones that can prevent the progression of arteriosclerosis by reducing plasma lipids. Furthermore, tofu is cholesterol-free and has a lower amount of saturated fat than animal sources of protein, such as meat or milk. Mixing different types of coagulants can potentially overcome the disadvantages of a single coagulant and improve the quality of tofu although research efforts have also explored new coagulants to replace traditional ones. Grape pomace (GP) can be used as a coagulating agent for tofu production. The GP, composed of a mix of grape seeds and skins, corresponds to approximately 62% of the total waste generated during the winemaking process. GPs are partially distilled for ethanol extraction, although most of this by-product is discarded, with several environmental and economic effects. Nevertheless, GPs are rich sources of high-value compounds, such as acids (tartaric, malic, and citric), fibres, polyphenols, and salts, and have been widely suggested as ingredients in pasta, puree, biscuits, yoghurt, cereal bars, pancakes, and cheese. Moreover, distilled GPs are rich sources of high-value compounds, although in contrast to fresh GPs, no applications have been suggested for distilled GPs; therefore, the problem of the disposal of fresh and distilled GPs still needs to be solved, and their use as ingredients in foods facilitates green production and the minimisation of by-product treatment costs, creating new sources of income for grape producers and increasing consumer interest in healthier foods. Furthermore, the addition of grape by-products to foods may represent a novel strategy to produce functional foods with high contents of polyphenols and high antioxidant activity. Since high concentrations of acids and salts are present in GPs, these by-products could act as coagulants for soy proteins. The possibility of their use in tofu production is very good in regard to reducing winemaking waste and obtaining new and innovative functional foods with high contents of polyphenols that are completely produced from vegetables.

Keywords: tofu ; grape pomace ; coagulation ; polyphenols ; radical scavenging activity ; texture ; consumer acceptability

1. Overview

Tofu, one of the most important products made from soymilk, is obtained through a coagulation process performed with various coagulants (acids, salts and, enzymes). Innovative tofu samples were produced using the grape pomace (GP) powders of different varieties (Barbera, Chardonnay, Moscato, and Pinot Noir) with different origins (fermented and distilled) at two concentration levels (2.5% and 5% *w*/*v*) as coagulants, and comparisons with traditional tofu were made. Physicochemical characteristics, phenolic contents, radical scavenging activity levels, textural properties, and consumer acceptability were evaluated. The moisture, protein content, and pH levels of GP tofu samples were slightly lower than those of traditional tofu. Regarding textural parameters, except for hardness, all other parameters were significantly lower in GP tofu samples, with differences due to GP concentration. The colours of GP tofu varied from amber-yellow to violet according to the GP origin. The blue-violet colours were observed predominantly in tofu samples obtained with Barbera and Pinot Noir GPs, while the other GP tofu samples showed amber-yellow colours. The concentrations of polyphenols were 2–10 times higher than in traditional tofu, while the radical scavenging activity levels were 9–80 times higher. The GP tofu samples were favoured by consumers, with small differences among the GP varieties.

2. Tofu

Tofu, soybean curd, or bean curd is one of the most important soya products and is produced by the addition of coagulants to soymilk. It is widely consumed in Asia and has been growing in popularity worldwide because of its high nutritional value, good texture, and unique flavour [1]. It has high contents of highly digestible proteins, dietary fibre, soy saponins, and isoflavones that can prevent the progression of arteriosclerosis by reducing plasma lipids [2][3][4]. Furthermore, tofu is cholesterol-free and has a lower amount of saturated fat than animal sources of protein, such as meat or milk [5].

There are two major steps in tofu production: heating soymilk and coagulation of soymilk to obtain a curd [1][6].

Heating soymilk causes denaturation of soy protein and exposure of the inner hydrophobic groups [7]. Electrostatic repulsion extensively opposes protein–protein interactions, preventing gel formation, while the balance of attraction and repulsion forces in protein molecules determines the stability of soymilk [7]. The heating of soymilk is also an essential step in the denaturation of antinutritional compounds [8]. Coagulation is then achieved by the addition of a coagulant, while hydrophobic interactions of the denatured protein lead to the aggregation of protein molecules, thereby forming curd [9][10].

The physical, textural, and sensory properties of the obtained tofu are affected by multiple factors that can be classified as intrinsic (i.e., composition of soya seeds) and extrinsic (i.e., processing conditions and packaging) factors [11][12][13]. The most critical step in the processing is the coagulation phase, which involves the selection of a coagulant [6][14][15][16]. At present, common coagulants are divided into three main groups: acids, salts, and enzymes [6][13]. The driving forces behind the acid gelation of soy proteins are isoelectric precipitation, including salt bridging, and direct interactions, such as hydrogen bonding and van der Waals forces [8][16]. With salts, a three-dimensional network structure is formed by forming salt bridges to cross-connect protein molecules [6]. In particular, phytic acids interact with Ca^{2+} to form non-ionising products that allow interactions between Ca^{2+} and proteins. Then, Ca^{2+} interacts with non-particulate proteins to form new protein particles, which are associated with each other to develop the gel network [17]. Enzyme coagulants such as transglutaminase can assemble proteins with the help of isopeptide bonds that are formed from the amine group in the glutamine residue and the ξ-amino group in the lysine residue [11]. Fermented soy whey, glucose-delta-lactone (GDL), and citric acid are commonly used acidic coagulants [6][14][16][18], while calcium sulphate, calcium chloride, calcium acetate, calcium lactate, and magnesium chloride are commonly used salt coagulants [5][19]. Magnesium chloride allows the taste of soybean to be retained and creates a more natural flavour for tofu; however, it is a quick-acting coagulant with a lower yield, forming a harder and non-uniform tofu [5].

Many studies have been devoted to evaluating the effects of these different coagulants on tofu quality. Shi et al. [6] studied the effects of four different coagulants (magnesium chloride, calcium sulphate, GDL, and fermented soybean whey) on the gelation behaviour of tofu, and their results showed a significant effect on the physicochemical properties, textural characteristics, and volatile flavour profile. In particular, the calcium sulphate tofu had the best overall acceptance in terms of sensory evaluation, while magnesium chloride tofu displayed the best gumminess, resilience, and mouthfeel.

Zhao et al. [18] evaluated the effects of different salts (potassium chloride, calcium chloride, and calcium sulphate) on the gelation of citric-acid-induced tofu and showed that this addition improved the mechanical properties of the product. In fact, the balance between forces that are suitable for gel structure leads to an increase in the storage modulus.

Cao et al. [16] studied the effects of different organic acids (citric, malic, and tartaric) on tofu quality, highlighting that tofu prepared with organic acids is comparable to that obtained with GDL, although the product prepared with tartaric acid had comparatively poorer physical properties and less robust chemical interactions. Acidification was also obtained with commercial lactic cultures, which in comparison with GDL showed a significantly earlier gel point but a similar final gel structure [8].

The structure and formation mechanism of tofu induced by different types of coagulants (GDL, calcium sulphate (CS), and microbial transglutaminase (MTGase)) were studied by Wang [20]. MTGase produced gels with an intermediate structure between CS and GDL but with the best uniformity. Similar work was performed by Rui et al. [21] who investigated the effects of different coagulants (GDL, magnesium chloride (MC), and MTGase) on the degradation of soybean proteins; their results showed that the MTGase tofu had the lowest protein digestibility when compared to the gels prepared with MC and GDL. Ezeama and Dobson [22] used Epson salt, lime, and tamarind to make tofu, showing that the fresh product obtained with Epson salt was well received by consumers because of its high calcium, magnesium, and protein contents.

Mixing different types of coagulants can potentially overcome the disadvantages of a single coagulant and improve the quality of tofu [1][5][13][18][20][23], although research efforts have also explored new coagulants to replace traditional ones. Crab shell powder [24], roselle water extract [25], trimagnesium citrate [26], papain [27], and commercial rennet have been used [28]. As highlighted by Zheng et al. [13], the use of a new coagulant requires not only the evaluation of its impacts on the compositional, textural, and sensory characteristics of tofu, but also its feasibility according to local availability and production costs; therefore, the purpose of this study was to evaluate the possibility of using grape pomace (GP) as a coagulating agent for tofu production. The GP, composed of a mix of grape seeds and skins, corresponds to approximately 62% of the total waste generated during the winemaking process [29]. GPs are partially distilled for ethanol extraction, although most of this by-product is discarded, with several environmental and economic effects [29]. Nevertheless, GPs are rich sources of high-value compounds, such as acids (tartaric, malic, and citric), fibres, polyphenols, and salts, and have been widely suggested as ingredients in pasta, puree, biscuits, yoghurt, cereal bars, pancakes, and cheese [29]. Moreover, distilled GPs are rich sources of high-value compounds, although in contrast to fresh GPs, no applications have been suggested for distilled GPs; therefore, the problem of the disposal of fresh and distilled GPs still needs to be solved, and their use as ingredients in foods facilitates green production and the minimisation of by-product treatment costs, creating new sources of income for grape producers and increasing consumer interest in healthier foods. Furthermore, the addition of grape by-products to foods may represent a novel strategy to produce functional foods with high contents of polyphenols and high antioxidant activity. Since high concentrations of acids and salts are present in GPs [29], these by-products could act as coagulants for soy proteins. The possibility of their use in tofu production is very good in regard to reducing winemaking waste and obtaining new and innovative functional foods with high contents of polyphenols that are completely produced from vegetables.

3. Conclusions

Tofu samples coagulated with Moscato and Chardonnay pomaces were very similar, with a “woody” colour and semi-solid texture. These tofu samples were characterised by a high quantity of sugars, similar to those obtained with fresh pomace. The tofu produced with the pomace of Pinot Noir was found to be the most consistent and dry. Finally, the tofu produced with Barbera pomace created some difficulties during production due to the formation of very fine curds, and consequently its soft and almost spreadable consistency. These two tofu samples were characterised by higher total polyphenol contents and radical scavenging activity levels. All of the obtained tofu samples were naturally coloured, and this characteristic is important from a commercial point of view. Generally, there were no differences between tofu samples according to the distillation process, while there were significant differences due to grape variety.

From the point of view of sensory characteristics, the tofu made using Barbera pomace had the greatest acceptability, although these results need to be confirmed by new and specific tests carried out with a greater number of consumers.

The tofu obtained with pomace is achievable on a technological level, as pomace naturally contains salts and acids; furthermore, since GPs are rich in polyphenolic compounds, they give tofu a functional value.

An ideal coagulant should be economical (i.e., affordable in most developing countries and especially in the least developed countries), convenient, have an efficient extraction rate, have possible use as an antioxidant, and have other functional properties, in addition to being highly nutritional and environmentally friendly. GPs have all of these characteristics, and the reuse of such pomaces in a new production process is valuable in order not to waste them. Their utilisation can also decrease the costs of winemaking.

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