p-ISSN: 1907-8056
e-ISSN: 2527-5410
AGROINTEK
Jurnal Teknologi Industri Pertanian
journal homepage: journal.trunojoyo.ac.id/agrointek

# Can poultry gelatin substitute bovine gelatin? : a systematic review and meta-analysis

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Article history
*Received:*
26 December 2022
*Revised:*
24 June 2023
*Accepted*:
25 June 2023

Keyword
*bovine gelatin;*
*chicken gelatin;*
*duck gelatin;*
*gel strength;*
*poultry gelatin;*

**ABSTRACT**

*Gelatin is one of the popular ingredients and additives in food industries. They have been applied in various roles, including stabilizers, thickeners, and emulsifiers. Bovine (cattle or cow) is one of the most widely used a source of gelatin. Unfortunately, they are still limited in particular considerations. For example, bovine gelatin is unacceptable in some Hindu communities. And the risks of Bovine Spongiform Encephalopathy (BSE) contamination, spreading, and outbreak related to bovine as a source. To challenge these limitations, poultry is another promising source. Current studies have found a similarity between poultry or chicken-based gelatin and bovine gelatin. However, investigation on the comparability of their gel strength is still rare. It is generally accepted that gel strength is the most essential characteristic of gelatin. This systematic review examined the gel strength between poultry gelatin and bovine gelatin. There were 795 papers screened, 29 full-text papers assessed, and 10 papers reviewed. The meta-analysis shows that chicken feet (CFG) and head (CHG) gelatin possessed a higher gel strength value than bovine gelatin. In contrast, the gel strength of chicken skin gelatin (CSG) and bovine gelatin did not differ significantly. The meta-analysis demonstrates that the gel strength of duck feet (DFG) and skin (DSG) gelatin is comparable with bovine gelatin. Thus, this study exposed the feasibility of CSG, DFG, and DSG, which can be the substitute for bovine gelatin.*



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DOI 10.21107/agrointek.v18i3.18051

## INTRODUCTION

Gelatin is a unique hydrocolloid (Schrieber and Gareis 2007), a fibrous protein (Zin et al. 2021; Zhang et al. 2021). This protein is colorless, tasteless, and brittle in a dry form. Gelatin is produced by partial hydrolysis of collagen (Rasli and Sarbon 2015; Mokrejš et al. 2019; Santana et al. 2021; Lueyot et al. 2021; Lu et al. 2022; Alipal et al. 2021; Mirzapour-Kouhdasht et al. 2021) obtained from skin, connective tissue, and animal bone (Siburian et al. 2020; Sousa et al. 2017; Gündem and Tarhan 2020; Teng et al. 2021). Gelatin has been widely applied in food industries, pharmacy, and photography (Haug et al. 2004; Karim and Bhat 2009; Sahilah et al. 2012; Nur Azira et al. 2014; Kadir et al. 2019). Schrieber and Gareis (2007) and Siburian et al. (2020) explained that the food industries are the largest gelatin consumer. In food, gelatin is a stabilizer, thickener, and emulsifier (Azilawati et al. 2015; Ahmad and Benjakul 2011).

Demand for gelatin has escalated remarkably in the food and pharmaceutical sectors (Santana et al. 2021). Data released by ReportLinker (2022) reported that the global gelatin market reached 504.8 thousand metric tons in 2020 and is estimated to rise by 799.5 thousand tons in 2026. The huge amount of gelatin is mainly extracted from the skin and bone of porcine and bovine (Yuswan et al. 2021; Schrieber and Gareis 2007; Shabani et al. 2015). Statista (2017) reported the gelatin from porcine and bovine skin reached 42.17% and 29.35%, respectively.

However, porcine gelatin use is restricted due to religious concerns among Moslems and Jews (Regenstein et al. 2003; Herpandi et al. 2011; Ardekani et al. 2013), while bovine gelatin is unacceptable by the Hindu community (Ardekani et al. 2013). Besides sociocultural factors, the constraint of bovine gelatin is related to health interests such as *Bovine Spongiform Encephalopathy* (BSE) (Dara et al. 2020; Herpandi et al. 2011; Jongjareonrak et al. 2005). Meanwhile, the rejection of porcine is closely associated with swine flu spread (Herpandi et al. 2011). Therefore, conformity of gelatin with religious law and health aspects shall be essentially guaranteed. Herpandi et al. (2011) argued the importance of seeking alternatives to conventional gelatin.

Several studies have extracted and characterized gelatin from traditional and alternative sources (Herpandi et al. 2011; Al-Hassan 2020). Among alternative sources that have been explored, fish gelatin extracted from the skin, bone, and scales of fish should be the most satisfying. Gomez-Guillen et al. (2002) reported that some features, including low stability and rheological properties, hindered much cold water fish gelatin. Gómez-Estaca et al. (2009) explained that fish gelatin had lower gel strength and yield than mammalian gelatin. The high gelatin strength is needed to manufacture hard capsule shells (Mustami et al. 2020).

In seeking an alternative gelatin source, poultry has also shown a tremendous result. As explained by Mrázek et al. (2019), poultry industries produce high amounts of by-products, such as skins, heads, feathers, viscera, bones, and feet. These discarded parts contain a high proportion of gelatin. Research on the extraction of poultry gelatin was reported, focusing on different parts of poultry, such as heads (Gál et al. 2020; Ee et al. 2019; Rahim et al. 2021), feet (Saenmuang et al. 2019; Rahim et al. 2021; Rahman and Jamalulail 2013; Mrázek et al. 2019; Miskiyah et al. 2020; Almeida et al. 2013), skins (Saenmuang et al. 2019; Aykın-Dincer et al. 2017; Sarbon et al. 2013; Xin et al. 2021; Abdullah et al. 2016; Chakka et al. 2017; Bichukale 2018), and bones (Khirzin et al. 2019; Hutapea et al. 2020). Other researchers also studied the optimum extraction condition for poultry-based gelatin (Rafieian et al. 2013; Elsanat et al. 2014; Erge and Zorba 2018) by considering the acid/alkaline solution concentration, temperature, and time.

Sarbon et al. (2013) reported the chemical similarity of chicken gelatin in comparison with bovine gelatin, while in some cases, the physicochemical features of poultry-base gelatin are more desirable than many fish gelatin. Kuan et al. (2016) studied the composition of amino acids and rheological properties of duck feet gelatin, finding comparable features with commercial bovine gelatin. Currently, studies concerning the comparison of gel strength between poultry gelatin (chicken and duck) and bovine gelatin are scarce. The gel strength is a key parameter of gelatin, as Ee et al. (2019) discussed, since it determines the proper use of gelatin. This study discussed the potential application of poultry gelatin as an alternative to bovine gelatin using systematic review and meta-analysis, focusing on gel strength as the parameter. Meta-analysis is a quantitative study blending various kinds of research to precisely construct a conclusion for a research question (Haidich 2010; Afandi 2020).

## METHODS

Systematic review and meta-analysis conformed to the procedures of Afandi et al. (2021) and Nitsuwat et al. (2021), consisting of 4 stages, i.e., literature search, selection and exclusion of articles, compiling of the database, and statistical analysis.

### Literature search

The systematic review procedure followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for identification, screening, eligibility, and article inclusion. Article sources included Google Scholar (using publish and perish principles), Science Direct, Wiley Online Library, Taylor & Francis Online, and Proquest. The literature search was limited to the following keywords: "*gelatin*," "*chicken,*" "*duck*," "*poultry*," "*gel strength*," and "*gelling*."

### Selection and exclusion of articles

The articles were screened using the criteria: parts of poultry, a method for gel strength measurement, mean availability, number of repetitions, standard deviation, and studies discussing bovine gelatin as a control. The part of poultry was clearly stated, while the gelatin extracted from the mixture of parts was unaccepted. Gel strength represented the force required to penetrate a standard plunger on a gel. The gel strength measurement method referred to the standard procedure prescribed by the Gelatin Manufacture Institute of America (GMIA), Gelatin Manufacturers of Europe (GME), and British Standards (BS 757:1975). The article shall contain the average, number of replications, and standard deviation. If needed, the direct question was asked to the author via the corresponding email. The eligible article also measured the gel strength of bovine gelatin as a control, using a similar method between samples. The inclusion criteria shall be entirely fulfilled in the systematic review, and the screened articles fit the criteria used in the meta-analysis.

### Compiling of database

Data extracted from eligible articles were compiled in Microsoft Excel, covering the type and parts of poultry used, gel strength average, standard deviation, number of replications, and procedure of gel strength measurement. In this context, poultry included chicken and duck as the most frequent poultry used in previous gelatin studies. We found one article discussing using quail for gelatin extraction reported by Samsudin et al. (2018). The parts of poultry included feet, skin, and heads. Using different extraction methods, the gel strength of gelatin from each procedure was compiled in a database.

### Statistical Analysis (meta-analysis and sub-group analysis)

OpenMEE software was applied for a meta-analysis, resulting in a forest plot displaying each article's effect size and 95% confidence interval and overall articles. The effect size was determined according to Hedge's d/Standard Mean Difference (SMD) using averages, standard deviation, and replications in each article. A random-effects model was applied in this work, considering the variability of gelatin extraction methods and differences in chicken and duck species. Sub-group analysis was performed according to parts of poultry in each species as a source of gelatin. The degree of heterogeneity between studies was determined using $I^2$ statistics, and the $I^2$ >50% represented sufficient heterogeneity. Variables in the sub-group analysis included poultry types and parts.

## RESULTS AND DISCUSSION

### Literature search and studies selection

Figure 1 shows the PRISMA flow chart describing the systematic review process. The titles collected from Google Scholar, Science Direct, Wiley Online Library, Taylor & Francis Online, and Proquest were 840 publications, and we collected 795 articles after removing 45 duplicates. The remaining articles were screened according to the title and abstract, resulting in 29 relevant articles. The 29 full-text articles were assessed for eligibility, and 21 were discarded due to data availability. Finally, we collected 8 eligible articles, then added 2 relevant records. The total articles included in the meta-analysis are 10 titles (27 studies).

In all selected publications (10 articles), which evaluated, they analyzed the gel strength of gelatin properly according to a standard method by using 6.67% gelatin solution and then the data presented in g.bloom. Gel-forming ability is a high-value material for human purposes such as food, medicine, and drug delivery formulation (Chettupalli et al. 2021). The gel strength is a pivotal physical characteristic of gelatin also. The type of gelatin sources provided different gelatin characteristics. So, by excluding the source of gelatin, three factors normally affect the gel strength of gelatin. They cover extraction methods (pretreatment and main extraction), molecular weight, and amino acid composition, with this last mostly correlated with hydroxyproline and proline (Hyp+Pro) concentration and ratio. The compilation of gel strength from 27 studies is presented in Table 1.

**Comparison of chicken and bovine gelatin**

There were 5 publications eligible to be examined. Among them, 4 articles also presented molecular weights and amino acid compositions of obtained gelatin. The gelatin is mostly extracted with water (45°C – 85°C). While during the pretreatment step, they used both alkaline and acid pretreatment, such as sodium hydroxide, sulfuric acid, acetic acid, lactic acid, and citric acid. In most occasions, gelatin's molecular weight (MW) data was presented in the form of a gel electropherogram then, the Mw of gelatin was precisely predicted based on protein standard (marker). The chicken-based gelatin has MW ranging between 110 kDa and 285 kDa. Most chicken gelatin exists in the form α-chain (110-130 kDa), some of them in α-chain and β-chain (dimers) or α-chain and ɣ-chain (trimers). None of the chicken gelatin contained all three forms of chain (α-, β-, and ɣ- chain) altogether. The β- and ɣ-chain have MW > 200 kDa. Interestingly, gelatin derived from chicken skin with MW 285 kDa, is one of the chicken-based gelatin that provides the highest gel strength (355 g.bloom) (Sarbon et al. 2013). This chicken skin gelatin has 25.7% imino acid (Hyp+Pro) means that it is in the company of the highest composition of imino acid. Concerning imino acid composition, chicken-based gelatin has various percentages ranging between 15.9 and 26.48% (skin), 19.7 and 22.6% (feet), and 22.98% (head).

Figure 2 depicts the forest plot of gel strength values for chicken and bovine gelatin as control. The standardized mean difference (SMD) of chicken feet gelatin (CFG) with bovine gelatin as control was 7.720 with a confidence interval (CI) of 95% between 0.471 and 14.969. The highest SMD was attributed to chicken head gelatin (CHG), i.e., 89.784, with the widest CI of 95% between 15.569 and 163.999. Conversely, chicken skin gelatin (CSG) showed the lowest SMD, i.e., 2.230, with a CI 95% of -2.558 to 7.018.

Between-study heterogeneity, expressed as $I^2$ statistics, showed a high score, namely 89.71%, 94.03%, and 85.2% for CFG, CHG, and CSG, respectively. The high degree of between-study heterogeneity for CFG, CHG, and CSG may result from differences in gelatin extraction methods between studies within a sub-group. This is noteworthy that the extraction process crucially dictates gelatin's gel strength, as Saenmuang et al. (2019) reported. Additionally, Valcarcel et al. (2021) explained that chemical treatments and temperature in the extraction phase could substantially alter the properties of gelatin.

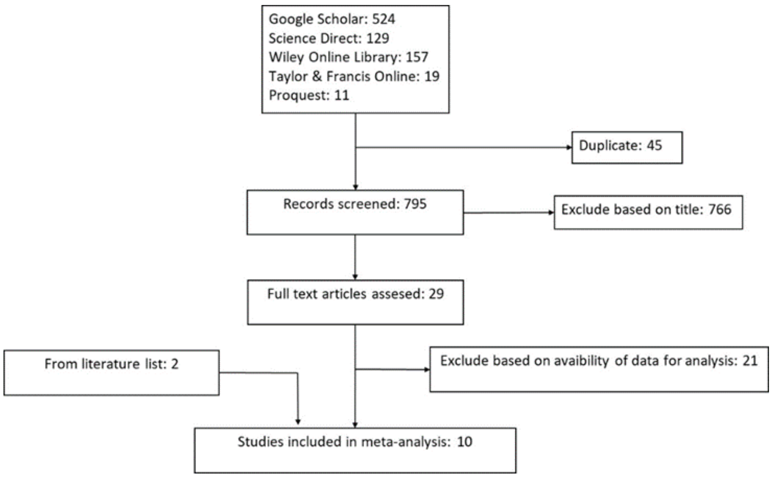


Figure 1 PRISMA flow diagram of the systematic review process

Table 1 The gel strength of poultry and bovine gelatin from 10 articles (27 studies) included in the meta-analysis

| Type of poultry | Part | Gel strength (g) of poultry gelatin | | Gel strength (g) of bovine gelatin | | References* |
|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | |
| Chicken | Feet (CFG) | 251.0 | 6.7 | 228.8 | 3.2 | Saenmuang et al. (2019) a |
| | | 254.3 | 5.9 | 228.8 | 3.2 | Saenmuang et al. (2019) b |
| | | 256.6 | 4.5 | 228.8 | 3.2 | Saenmuang et al. (2019) c |
| | | 356.00 | 1.00 | 152.00 | 0.60 | Rahim et al. (2021) a |
| | | 268.00 | 1.10 | 152.00 | 0.60 | Rahim et al. (2021) b |
| | Head (CHG) | 355.77 | 0.33 | 190.64 | 1.86 | Ee et al. (2019) a |
| | | 332.40 | 4.28 | 190.64 | 1.86 | Ee et al. (2019) b |
| | | 38.62 | 3.25 | 190.64 | 1.86 | Ee et al. (2019) c |
| | | 320.00 | 0.10 | 152.00 | 0.60 | Rahim et al. (2021) c |
| | | 230.12 | 0.30 | 152.00 | 0.60 | Rahim et al. (2021) d |
| | Skin (CSG) | 263.5 | 3.9 | 228.8 | 3.2 | Saenmuang et al. (2019) d |
| | | 249.1 | 9.9 | 228.8 | 3.2 | Saenmuang et al. (2019) e |
| | | 239.0 | 6.7 | 228.8 | 3.2 | Saenmuang et al. (2019) f |
| | | 166.65 | 1.63 | 238.25 | 2.47 | Aykın-Dincer et al. (2017) |
| | | 355 | 1.48 | 229 | 0.71 | Sarbon et al. (2013) |
| Duck | Feet (DFG) | 225.53 | 6.5 | 216.63 | 4.54 | Muhammad et al. (2018) a |
| | | 334.17 | 1.29 | 216.63 | 4.54 | Muhammad et al. (2018) b |
| | | 322.17 | 3.60 | 216.63 | 4.54 | Muhammad et al. (2018) c |
| | | 322.63 | 4.10 | 216.63 | 4.54 | Muhammad et al. (2018) d |
| | | 209.63 | 5.29 | 232.63 | 2.01 | Kuan et al. (2016) |
| | | 63.78 | 0.15 | 150.71 | 0.52 | Zain et al. (2020) a |
| | | 285.05 | 0.00 | 150.71 | 0.52 | Zain et al. (2020) b |
| | | 139.87 | 0.00 | 150.71 | 0.52 | Zain et al. (2020) c |
| | Skin (DSG) | 364.10 | 3.10 | 224.20 | 3.03 | Teng et al. (2021) a |
| | | 205.13 | 1.46 | 224.20 | 3.03 | Teng et al. (2021) b |
| | | 143.86 | 4.77 | 115.47 | 2.56 | Kadir et al. (2020) a |
| | | 143.61 | 5.50 | 115.47 | 2.56 | Kadir et al. (2020) a |

Furthermore, the results showed that CFG and CHG had significantly different gel strengths than bovine gelatin (with $p < 0.01$ and 95% CI not passing the null effect line). Based on the SMD value, CFG and CHG displayed a higher gel strength than bovine gelatin. Nagarajan et al. (2012) argued that the gel strength of gelatin could vary greatly between sources, depending on the composition of amino acids as one of the critical factors. Rafieian et al. (2015) reported that low gel strength is related to the low proportion of hydroxyproline and proline. In addition, Saenmuang et al. (2019) also revealed that the abundance of amino acids in CFG is higher than in bovine gelatin for all extraction processes. The gel strength for CSG is comparable with bovine gelatin (with $p < 0.01$ and 95% CI passing the null effect line). Concerning this feature, Mrázek et al. (2019) stated that CSG could be potentially applied as a substitute for porcine and bovine gelatin. CSG also displays a better viscosity, fat-binding ability, and foam stability than mammalian gelatin. However, it is still inferior to bovine and porcine gelatin in terms of water-binding capacity, emulsifying stability, and foaming agent. Suderman et al. (2018) mentioned that CSG-based films' characteristics are superior, making them desirable as an alternative to commercial mammalian gelatin.

### Comparison of Duck Gelatin and Bovine Gelatin

In comparing duck gelatin and bovine gelatin according to inclusion criteria, 5 full-text publications (2 original articles and 3 proceeding conferences) were eligible. Two articles were about duck skin gelatin, and 3 articles were about duck feet gelatin. Duck-based gelatin was extracted using warm (55-75°C) and hot water with prior treatment by alkaline (sodium hydroxide) and acid (hydrochloric acid, acetic acid, citric acid, and lactic acid). The time for pretreatment and main extraction were also various. For instance, the pretreatment of duck feet with acetic acid was 16 h, then extracted with water for 12 h, while the pretreatment of duck skins with acid solvent was 24 h, followed by 2 h main extraction on warm water. There are limited studies on investigating and estimating MW of obtained duck gelatin. The study conducted by Kuan et al. (2016) identified that duck feet consist of α-chain and β-chain forms of gelatin by electroforegram gel. However, this study also found protein fragments less than 66.2 kDa may be caused by gelatin hydrolysis and degradation during extraction methods.

Furthermore, for the imino acid composition, duck-based gelatin contains imino acid, around 22.54-23.14%. The imino acid in collagen is around 23% (El Blidi et al. 2021). Collagen is also among the most biocompatible and safe materials for humans and animals (Blagushina et al. 2021). This means there is no imino acid degradation or hydrolysis during collagen-to-gelatin conversion in the extraction process. In other words, the extraction method is the preferred method for extracting gelatin without hydrolyzing or degrading the imino acids assuming they do not change the gel strength of gelatin compared to the predecessor one (the collagen). Some studies only quantified the hydroxyproline composition on duck gelatin. Teng et al. (2021) found that the hydroxyproline content in duck skin gelatin ranged from 10.25-13.84%, while hydroxyproline in bovine gelatin was 12.87%. This study clearly stated that the gel strength of duck gelatin with high composition hydroxyproline was higher than lower hydroxyproline content on bovine gelatin and duck skin gelatin.

Figure 3 depicts a forest plot comparing gel strength between duck gelatin and bovine gelatin in meta-analysis. SMD for duck feet gelatin (DFG) with bovine gelatin as control reached 5.242 with CI 95% of -3.591 to 14.075, being higher than that for duck skin gelatin (DSG), namely 3.854, with CI 95% of -3.554 to 11.263.

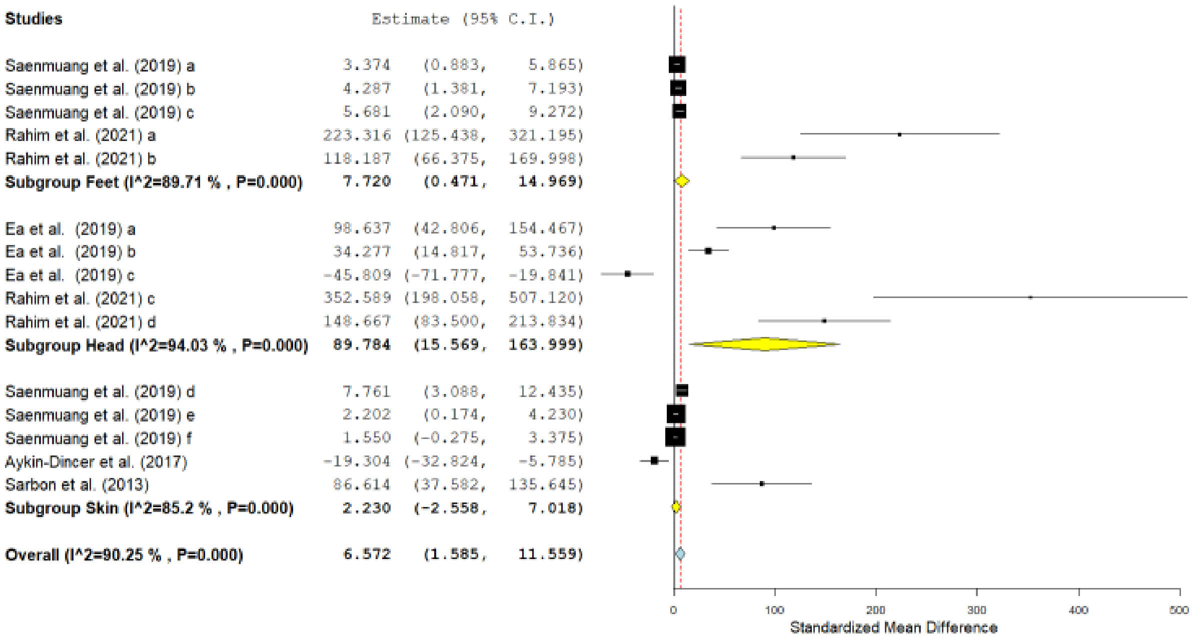


Figure 2 Forest plot of meta-analysis on comparison of gel strength between chicken gelatin and bovine gelatin by random-effect model

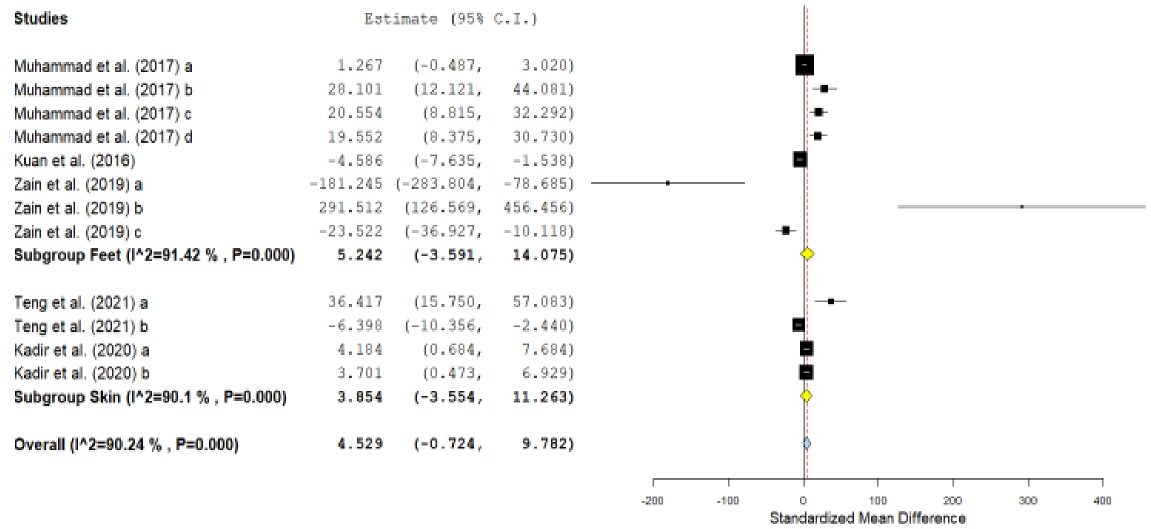


Figure 3 Forest plot of meta-analysis on comparison of gel strength between duck gelatin and bovine gelatin by the random-effect model

Heterogeneity between studies for DFG and DSG was also high, reaching 91.42% and 90.1%, respectively. The high level of between-study heterogeneity for DFG and DSG may display the variety of extraction methods. Park et al. (2013) reported that the characteristics of DFG relied highly on the extraction procedure. Besides, duck species can be an essential factor in altering the quality of gelatin. In the papers reviewed, duck species included Pekin, Muscovy, Khaki Campbell, and other species not mentioned in the articles. Muyonga et al. (2004) found that the composition of amino acids could differ greatly between species. The profile of amino acids in gelatin is essential since it determines gel strength (Gomez-Guillen et al. 2011). The gel strength is strongly influenced by the molecular weight distribution, mainly determined by the processing conditions (Noor et al. 2021).

Gel strength for DFG and DSG did not differ significantly compared with bovine gelatin as a control (with $p < 0.001$ and 95% CI passing the null effect line). This means that DFG and DSG can serve alternative gelatin to bovine gelatin with similar gel strength. Zain et al. (2020) mentioned that DFG can replace conventional gelatin. It is reported that the physicochemical and functional properties of DFG approximate to bovine gelatin (Kuan et al. 2016).

## CONCLUSION

The results of the meta-analysis showed that CFG and CHG had a higher gel strength than bovine gelatin, while the gel strength of CSG is comparable with bovine gelatin. SMD for CFG, CHG, and CSG with bovine gelatin as control reached 14.969, 89.784, and 2.230, respectively. The meta-analysis results also show that gel strength between duck gelatin (DFG and DSG) and bovine gelatin did not differ significantly. SMD for DFG and DSG with bovine gelatin as control reached 5.242 and 3.854, respectively. There are three categories of gelatin, namely high gel strength (220-300 or >300 g.bloom), medium gel strength (150-220 g.bloom), and low gel strength (<150 g.bloom) (Hanani 2016). Poultry gelatin is dominated by high-gel-strength gelatin. In conclusion, this study reveals that poultry gelatin products, namely CSG, DFG, and DSG, can substitute bovine gelatin.

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