dried tomato pomace (contains 31% fibre) may be incorporated at 15% in laying hen diets, while such pomace may only be included in broiler rations at the maximum of 5%. The better capability of laying hens in degrading fibre than of broilers seems to be the reason for the higher fibre digestibility (and thus intake of fibre-rich feedstuffs) in laying hens. Moreover, laying hens seem to have lower energy requirement compared to broiler chickens. This makes laying hens more tolerant to cassava pulp (Diarra and Devi, 2015). Within each broiler and laying hens, the variations in the optimal dietary levels of cassava pulp also existed. In such case, several factors may determine the variation, including the nature (e.g., nutritional composition) of cassava pulp, dietary composition, energy to protein ratio of rations, strains of chickens and other experimental conditions.

Aside from the high energy content, cassava pulp generally contains high and low contents of fibre (13.6%) and protein (1.98%), respectively (Khempaka et al., 2009). According to Morgan and Choct (2016), most of the fibre in cassava pulp is counted as insoluble fibre. The latter properties may, therefore, limit the use of cassava pulp in poultry rations, as poultry has a very limited capacity in degrading the insoluble fibre. High fibre fraction in cassava pulp may also increase the bulkiness of the diet and therefore limit the capacity of the digestive tract of chickens. This condition may eventually reduce palatability and feed intake in chickens (Khempaka et al., 2009). To elevate the dietary inclusion level of cassava pulp, supplementation of enzymes have been conducted. Khempaka et al. (2018) have recently supplemented dried cassava pulp with mixed enzymes containing cellulase, glucanase and xylanase in laying hens. Such enzyme supplementation could increase the inclusion level of dried cassava pulp from 20% (Khempaka et al., 2016) to 30% (Khempaka et al., 2018) in laying hen diets. The activity of enzymes in degrading the fibre fraction of cassava pulp may increase the digestibility of such feed ingredient and thus increase the feed intake of chickens (Khempaka et al., 2018).

**Table 1.** The use of dried cassava pulp in chicken diets

| References | Findings and recommendations |
|---|---|
| Khempaka et al. (2009) | Dried cassava pulp should be limited to 8% or less, as higher inclusion level may compromise the growth performance of broiler chickens. |
| Kumsri et al. (2009) | Dietary inclusion of 10% dried cassava pulp reduced weight gain of broiler chickens. |
| Ali-Mursyid et al. (2010) | Dried cassava pulp may be incorporated in broiler rations at a maximum of 11%, higher inclusion level may be detrimental for the growth of broilers. |
| Tang et al. (2012) | Feeding dried cassava pulp at a level of 25% resulted in poor growth performance in broiler chickens. |
| Triprugsachart et al. (2007) | Feeding dried cassava pulp up to 15% represented no detrimental impact on egg production of laying hens. |
| Chauynarong et al. (2010) | Dietary incorporation of dried cassava pulp up to 15% had no deleterious effect on egg production of laying hens. |
| Khempaka et al. (2016) | Dried cassava pulp can be included up to 20% in laying hen rations with no negative impact on productive performance, nutrient digestibility, and egg quality. |
| Khempaka et al. (2018) | Dried cassava pulp supplemented with mixed enzymes (cellulase, glucanase and xylanase) may be included in laying hen feeds up to 30% with no detrimental effects on nutrient digestibility, productive performance and egg quality. |

**Fungal fermentation to improve the nutritional characteristics of cassava pulp**

Fermentation is a simple process using microorganisms to break down the complex substrates into simpler components (Sugiharto and Ranjitkar, 2019). Eventually, the degraded compounds maybe utilized maximally by the chickens. Depending on the microorganisms involved, supplements added, duration of the fermentation process and other fermentation conditions, there is a slight variation in the improvement of the nutritional quality of cassava pulp particularly with regard to protein and fibre contents. It appears from the documented studies that fungi (Filamentous fungi and yeast) are the most common microorganisms employed to ferment cassava pulp. The definite reason for such preference is not specifically known. There are several traits belong to fungi that may be exploited to improve the nutritional properties of cassava pulp, one of which is its fibrinolytic activity. A study by Mustafa et al. (2016) noticed that treatment with fungi was capable of degrading the insoluble fibre (lignin and hemicellulose) resulting in reduced fibre content of the substrates. Such fibre degradation may be facilitated by the activity of extracellular cellulases produced by the fungi (Bhardwaj et al., 2017). The cellulolytic activity of the fungi may also transform the cellulosic compounds into protein, and therefore increase the protein content of materials. In such case, the conversion of fibre into protein-rich fungal biomass may be responsible for the increased protein content of the fungal fermented products (Asadollahzadeh et al., 2018). In addition, Bayitse et al. (2015) suggested that simple sugars may also be metabolized to protein resulting in an increase in protein content of the fermented products. Apart from the improved fibre and protein contents, fermentation has been known to result in the reduction of Hydrogen Cyanide (HCN) (Diarra and Devi, 2010).

To increase the protein content of FCP, supplementation using urea during fermentation has commonly been conducted (Table 2). During the fermentation process, urea may be used as a nitrogen source for the fungal growth (Bayitse et al., 2015). Such an increase in fungal biomass may thereby increase the protein content of the fungal fermented products. In most cases, fungal fermentation of cassava pulp has been carried out according to the solid-state fermentation method. This fermentation method is characterized by the low content of moisture in the substrates (Sugiharto and Rajitkar, 2019). Indeed, there is no specific reason on why solid state fermentation is more attracted to be employed in the fungal fermentation of cassava pulp. Yet, Gowthaman et al. (2001) suggested that solid-state fermentation may better support the fungi to grow on complex natural solid substrates without substantial pretreatment.

**Table 2.** Nutritional characteristics of fungal fermented cassava pulp

| References | Microorganisms involved in fermentation | Supplement in fermentation | Characteristics of fermented cassava pulp |
|---|---|---|---|
| Lubis et al. (2007) | *Aspergillus niger* | None | Crude protein content increased from 2.21 to 3.58% and crude fibre increased from 11.2 to 17.0% |
| Thongkratok et al. (2010) | *Aspergillus oryzae* | Urea | Protein and amino acid contents increased by 17.4 and 15.1%, respectively |
| Animashahun et al. (2013) | *Penicillium* spp. | None | Crude protein increased from 2.39 to 3.25% and crude fibre decreased from 11.4 to 9.63% after 7 days of fermentation |
| Khempaka et al. (2014) | *A. oryzae* | Urea | Crude protein increased from 2.02% to 11.8%, whereas crude fibre decreased from 14.6% to 10.6% |
| Bayitse et al. (2015) | *Trichoderma pseudokoningii* (ATCC 26801) | Urea and ammonium sulphate | Protein content increased by 48.1% and 36.9% with supplementation of urea and ammonium sulphate, respectively |
| Sugiharto et al. (2015) | *Acremonium charticola* | None | Crude fibre decreased from 18.4% to 16.9%, while crude protein did not significantly change (compared to unfermented cassava pulp) |
| Sugiharto et al. (2015) | *Rhizopus oryzae* | None | Crude fibre decreased from 18.4% to 17.6%, while crude protein did not significantly change (compared to unfermented cassava pulp) |
| Sugiharto et al. (2016) | *A. charticola* | Urea | Crude protein increased from 2.14% to 11.3%, while crude fibre decreased from 25.6% to 20.8% |
| Sugiharto et al. (2016) | *R. oryzae* | Urea | Crude protein increased from 2.14% to 12.8%, while crude fibre decreased from 25.6% to 22.7% |
| Sengxayalth and Preston (2017) | *Saccharomyces cerevisiae* | Urea and di-ammonium phosphate | Crude protein increased from 9.5 to 18.4% and true protein increased from 2 to 12% dry matter |
| Okrathok et al. (2018) | *A. oryzae* | Urea | Crude protein increased from 1.98% to 13.3%, true protein increased from 0.98% to 12.4% and crude fibre decreased from 13.6% to 10.7% |
| Yafetto (2018) | *A. niger* | Ammonium nitrate | Crude protein increased by 22.61% |

**The use of fungal FCP in chicken diets**

Fungal fermentation has been attributed to the improved nutritional qualities of cassava pulp. As a consequence, fermentation can increase the inclusion levels of cassava pulp in chicken rations. As shown in Table 3, FCP may be included in broiler and laying hen rations greater than that of unfermented cassava pulp. However, the levels of FCP inclusion may vary from study to studies depending on the nutritional qualities of FCP, dietary composition and other experimental conditions. In most cases, there is a positive correlation between nutrient digestibility and feed intake in chickens (Sundu et al., 2006). In light with this, the improved nutritional qualities in FCP (especially the reduced fibre content) may be attributed to the reduced bulkiness and increased digestibility and thereby increased feed intake in chickens (Khempaka et al., 2014). Fermentation has been suggested to improve the palatability of products (Supriyati et al., 2015). In this respect, better palatability of FCP may be one of the reasons for the increased FCP intake in chickens when compared with the intake of unfermented cassava pulp. The toxicology of liver due to urea supplementation (during fermentation process) and the presence of toxic compounds such as HCN in cassava pulp may be a crucial point of consideration when using FCP as a dietary ingredient for chickens. In conjunction with Khempaka et al. (2014), we assessed the activities of aspartate aminotransferase (AST) and alanine aminotransferase (ALT) as indicators of liver health and found no change in the activities of these enzymes when feeding FCP as compared to control (Sugiharto et al., 2017b). The bioconversion of urea to fungal biomass protein (Bayitse et al., 2015) and the destruction of HCN during the fermentation process (Diarra and Devi, 2010) may implicate in safe inclusion of FCP in chicken diets.

**Table 3.** The levels of FCP inclusion in chicken rations

| References | Recommended levels of FCP inclusion |
|---|---|
| Lubis et al. (2007) | *A. niger*-FCP-urea-zeolite may be used in diets up to 15% without negative impacts on growth performance and health of broilers. |
| Ali-Mursyid et al. (2010) | FCP could be included in diets up to 16.5% without detrimental effects on growth performance and nutrient digestibility of broiler chicks. |
| Khempaka et al. (2014) | *A. oryzae*-FCP can be included up to 16% in the rations with no deleterious effects on nutrient digestibility and retention, final body weight, carcass traits and biochemical parameters. |
| Sugiharto et al. (2017a) | *A. charticola*-FCP can be included up to 16% with no adverse effects on final body weight, digestibility and carcass characteristics of broiler chickens |
| Okrathok et al. (2018) | *A. oryzae*-FCP was safe to be included up to 24% in diets without deleterious effects on nutrient digestibility, egg production and quality and physiological conditions of laying hens |

### Functional properties of FCP as a dietary component in chicken diets

Fermented products have been attributed to functional properties such as higher lactic acid bacteria (LAB) and organic acids contents. These properties make FCP beneficial for the health of the gastrointestinal tract of chickens (Sugiharto and Ranjitkar, 2019). Regarding to the effect of FCP on chicken health, the published data are still scarce. A recent study by our research group revealed that *A. charticola*-FCP decreased coliform bacteria count in the ileum and increased butyric and propionic acid concentrations in cecal contents of broiler chickens (Sugiharto et al., 2017a). The capacity of LAB and organic acids in controlling the proliferation of potentially pathogenic bacteria such as coliform may be responsible for the reduced population of such pathogenic bacteria in the intestine of chickens fed FCP. To increase the functionality of fermented products, fermentation using probiotic microorganisms (as starter inoculum) has been conducted (Sugiharto and Ranjitkar, 2019). In this respect, fermented products may not only have improved nutritional qualities, but also contain higher numbers of probiotic microorganisms. Due to the limited data, the study on the functional effect of FCP on chickens needs to be extensively conducted.

## CONCLUSION

Solid-state fermentation using fungi can be a simple method to improve the nutritional qualities of cassava pulp and thus increase the inclusion level of such cheap agro-industrial by-product in chicken rations. Further studies are needed to explore the functional benefit of FCP on chicken health.

## DECLARATIONS

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**Competing interest**

I have no conflict of interest.

**Consent to publish**

I gave my consent prior to publication of this article.

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