

Utilization of Beetroot By-Products in Pasta Production: A Nutritional and Sustainable Approach

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Beetroots (*Beta vulgaris* L) and their by-products, constitute a considerable agricultural waste stream, with an estimated annual production of around 14 million tons of beetroot stalks (Abdo *et al* 2023). Despite the substantial quantity of this waste, beetroot stalks are recognized as a valuable source of bioactive compounds, including polyphenols such as rutin, quercetin, catechin, vanillin, syringic acid, and ellagic acid, as well as betalains, which can reach levels of up to 6.59 mg/g. This positions them as a highly beneficial yet underexploited agricultural by-product (de Oliveira *et al* 2023; Dos Santos *et al* 2018). Additionally, these stalks are abundant in dietary fibers, vitamins, and minerals, making them an economical and sustainable food additive. When incorporated into food products, beetroot stalks not only impart a natural red hue but also offer significant health advantages due to their antioxidant and anti-inflammatory properties. When incorporated into food products, beetroot stalks provide a natural red color and offer substantial health benefits due to their antioxidant and anti-inflammatory properties.

As consumer awareness regarding the adverse effects of synthetic colorants grows, food manufacturers are progressively turning to natural alternatives to improve the colour and quality of their products. The vibrant red hue of beetroot stalks presents an excellent option for this transition towards cleaner-label offerings. Beyond their ability to enhance colour, these by-products are also beneficial for health, as they are rich in valuable components, thereby serving as an attractive choice for food fortification. (Abdo *et al* 2023; Echegaray *et al* 2023).

Pasta, one of the most widely consumed foods globally, offers a promising matrix for enhancing its nutritional content through the addition of vegetable by-products. Enriching pasta dough with beetroot and other plant-based waste materials can significantly enhance its nutritional profile. However, the inclusion of vegetable-derived components in pasta formulations can alter the rheological properties of the dough, weakening the gluten network and interfering with starch gelatinization (Oliviero and Fogliano, 2016). This disruption can affect the texture and sensory properties of the final product. Additionally, the drying and cooking processes of pasta can lead to the degradation of heat-sensitive bioactive compounds, with water-soluble nutrients being lost into the cooking water, potentially diminishing the nutritional benefits of the enriched pasta (ElGamal *et al* 2023; Oliviero and Fogliano, 2016).

The aim of this study is to investigate the feasibility of replacing conventional semolina with beetroot stalk powder in the production of pasta. This initiative seeks to minimize food waste, encourage the utilization of innovative by-products from the food industry, and enhance the nutritional quality of pasta. Beetroot stalks, which are frequently regarded as agricultural waste due to their low market value and the general unawareness of their nutritional benefits, have the potential to be incorporated as a sustainable and functional ingredient in pasta. The addition of beetroot stalks not only offers nutritional advantages but also improves the aesthetic appeal of the pasta through its vibrant red hue, potentially increasing its consumption, especially among children. This approach is in line with the growing consumer preference for healthier, functional food options.

A series of experiments was carried out to evaluate the effects of replacing semolina with different proportions of beetroot stalk powder on the physicochemical and sensory properties of enriched pasta. The beetroot stalks were first dried at 40°C to prevent the degradation of thermolabile components, resulting in a powder with a moisture content of approximately 5%. This powder was subsequently incorporated into pasta formulations, substituting semolina at varying levels (5-20%). The enriched pasta was analyzed for several parameters, including moisture content, color, total phenolic content, and antioxidant capacity, as well as physicochemical properties such as hardness, cohesiveness, elasticity, and adhesiveness. Additionally, a sensory evaluation was conducted to assess how the substitution influenced the organoleptic attributes (color, aroma, texture, and consumer acceptance) of the final products.

The results revealed that increasing the proportion of beetroot stalk powder in pasta formulations resulted in a notable enhancement of total phenolic content and antioxidant capacity, with the highest values recorded at a 20% substitution level. A positive relationship was identified between the quantity of beetroot stalk powder and the antioxidant capacity of the pasta. Furthermore, an increase in the proportion of this by-product powder corresponded with a rise in the moisture content of the pasta, attributable to the hygroscopic properties of the fibers and carbohydrates found in the stalks. In terms of sensory characteristics, pasta fortified with beetroot stalk powder displayed a darker brown hue relative to the control sample, with the color intensity increasing in accordance with the level of substitution.

In terms of rheological characteristics, pasta with a 10% substitution demonstrated the greatest hardness, suggesting an ideal equilibrium between enhancement and structural stability. Conversely, the inclusion of beetroot stalk powder diminished the cohesiveness of the resulting pasta. Elasticity was consistent across all samples, whereas adhesiveness showed an increase, a trait that is typically considered unfavorable at elevated substitution levels in pasta.

In conclusion, the incorporation of beetroot stalks into enriched pasta presents a viable approach to enhance the nutritional profile, aesthetic appeal, and sustainability of this widely consumed food item. The results of this study underscore the significance of these by-products as a valuable yet underexploited resource for fortifying pasta, thereby improving its health benefits. The effective integration of beetroot waste in pasta manufacturing could serve as a paradigm for advancing sustainability and addressing the increasing consumer interest in innovative, healthier, and functional food options.

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