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Full Length Research Paper

Development and Testing of a Novel Semi-Automatic Machine for the Production of Powdered Tomatoes

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ABSTRACT: Increasing food production or decreasing post-harvest losses improves food security. Harvesting, cooling, storage, infrastructure, packaging, and marketing systems contribute to pre-consumer food losses. Poor food supply chain management, seasonal production fluctuations, and farmers and intermediaries preferring urban markets over processors due to low farm gate prices are estimated to be annual losses of over 45 percent (750,000 metric tonnes) of tomatoes produced in Nigeria. This study designed, built, and tested an innovative tomato powder processing plant. After extensive research, a new semi-automatic machine for powdering tomatoes was technically and economically feasible. Engineers, environmentalists, and personal safety professionals can address any safety concerns. Researchers designed a plant to process 1 kg of raw tomatoes per day. Twelve hours per day, 280 days per year, 140 kg of tomato powder was produced. The best process route was synthesised from these specifications. Solar thermal drying (as a drying process) was chosen for the process route. To dry tomato powder on an industrial scale, researchers found that spray-drying was the most efficient, low-cost and straightforward method. Controlling particle size was also simple with this technology. The system included a blanching machine, a solar thermal dryer, and a blender.

Keywords: Tomato powder, fabrication, storage, semi-automatic machine, spray-drying

INTRODUCTION

Tomatoes are a significant source of L-ascorbic acid, lycopene, and other carotenoids in the human diet (Beecher, 1998; Liu et al., 2010). Consumption of tomato and tomato-based products has been linked to a reduced risk of certain cancers, including the digestive tract and prostate cancer, possibly due to lycopene and other antioxidant components (Liu et al., 2010; Tapiero et al., 2004). Antioxidant properties of lycopene (the most abundant carotenoids in tomatoes) and other functional components have increased interest in tomato consumption. Like most fruits and vegetables, Tomatoes produce surpluses during the growing season and deficits during the off-season (Cernîsev, 2010; Liu et al., 2010). Insufficient processing facilities and short shelf-life result in revenue loss. Thus, commercially, tomato preservation and processing are essential (Liu et al., 2010). Due to their excellent properties, dried tomato products (tomato halves, slices, and powders) are consumed more than other tomato products (Liu et al., 2010; Martins et al., 2020). Among these dried tomato products, powder stands out. Powdered tomato solids have many advantages, including ease of packing, transportation, and mixing (Giovanelli et al., 2002; Liu et al., 2010). Tomato powder is also in high demand by dehydrated soup manufacturers and is an ingredient in many foods, mainly soups, sauces, and ketchup (Liu et al., 2010). Several authors have studied the effects of different processing and storage conditions on dried tomato products' chemical and

physical properties (Liu et al., 2010).

Dried tomato products change during processing and storage. Tomato powder's moisture content, bulk density, and solubility depended on the spray drying conditions, i.e. air inlet temperature, drying air flow rate, and compressed air flow rate (Goula and Adamopoulos, 2005; Roos and Drusch, 2016). Lycopene is a valuable quality indicator for tomato products, and studies show that heating and drying tomato products to make tomato powder degrades lycopene (Goula et al., 2006; Liu et al., 2010). The rate of colour formation increased as the intensity of the drying process increased (Gaudel et al., 2022; Liu et al., 2010). Glass transition temperature (Tg) is correlated to physical changes such as flow-ability and cohesion in food powders (Liu et al., 2010).

Due to low molecular weight solutes, osmotically treated, air-dried tomatoes had lower glass transition temperatures than freeze-dried tomatoes (Liu et al., 2010). After that, the product should be stored in metalized polyester bags to protect it from light, oxygen, and humidity and slow down the quality changes (Cernîsev, 2010).

Tomato is a red edible fruit with high nutritional value and culinary versatility. But it spoils quickly. According to Olarenwaju (2016), 65 percent of Nigerian tomato production spoils. Tomato is the most popular vegetable in today's home gardens and obviously the most commonly consumed vegetable fruit in meals. In Nigeria, tomatoes are grown on large and commercial scales in the North but consumed equally across the length and breadth of the entire country (Olayemi et al., 2010). Dried tomatoes are currently produced by direct drying in the sun and the open, but they are more durable without additives. The finished result is unclean to eat, infested with soil and grit. Though dissuading this activity, concerted efforts have been made through agencies and research institutions to establish an economical technology for dried tomato flakes and powder development.

Development and testing of a novel, semi-automatic tomatoes powder production machine were carried out, and it was concluded that it is technically feasible, the process routes are possible, and process conditions are attainable. The best way to produce the tomato powder on an industrial scale is using the Spray drying method. This method was chosen because it is very rapid, requires low labour cost, is relatively easy to carry out, and can easily control the product's particle size. A solar thermal dryer is used for this novel technology to evaluate if there can be a significant difference in performance over the spray drying technology.

The seasonal excess experienced at each harvest, apart from marking the extremes of wastage of produce, dampens the farmer's spirit to farming as he is forced to sell off produce at a loss to avert imminent total wastage. To curb this massive wastage occasioned by harvest, the government tries to find a lasting solution to the problem through its various agencies. Canning of tomato paste has helped to curb wastage. Still, the industry's capital-intensive nature, the alteration in the taste of the product canned (as additives are added to aid in preservation), the bulky nature of the paste product, and poor durability have all contributed to limiting the establishment of canning industries. As a result, only a tiny percentage of the product is absorbed by this industry. Dried (powdered) tomatoes though more durable and without any need for additives, are currently produced by direct drying in the sun and the open. The end product is infested with dirt and sand, making it unhygienic to consume (Ayandiji *et al.,* 2011).

Objective

The aims and objectives of the design project were to address the challenges that arose as a result of the perishable qualities of tomatoes by:

To subject samples of fresh tomatoes to a different combination of modern drying methods (passive solar dryer cum microwave drying).
To investigate the effects of these novel drying methods on the quality parameters of dried tomatoes.
To design a process that will enhance the production of powdered tomato.

RAW MATERIALS AND PRODUCT SPECIFICATION

Tomato comes from the kingdom *Plantae*, the family *Solanacaea* and the genus, *Solanium*. Its botanical name is *Lycopersicon esculentum*. It grows well in loamy soil and thrives better in soil with an acidic pH. The tomato is a major vegetable crop that has achieved tremendous popularity over the last century (Kaminski and Christiansen, 2014). Despite tomato's nutritional and medicinal value, preservation is a significant problem as it spoils a few days after harvest. Drying is one of the oldest methods of preserving agricultural products. Conventional dryers like cabinet dryers, sun drying, tunnel dryer, hot air dryer and oven dryer have been found to have adverse effects on agricultural products (Fernandes and Sueli, 2007). Recently, novel dryers like the infrared dryer, ultrasound-assisted osmotic dryer, microwave dryer, vacuum dryer and freeze dryer can preserve the quality parameters of dried agricultural products (Onwude et al., 2017).

The varieties of tomatoes available in the market included: Dandino, Danyeka, UTC, Roma, Ibadan local etc. They had different tastes and colours. For quality and attractive production, varieties can also be blended, such as Dandino (having the sweetest taste) and UTC (having the brightest deep red colour). The best species of tomatoes grown or cultivated in Nigeria are the ROMA TOMATOES. These acid tomatoes are known for their chewy flesh and relatively low water content, about 93% moisture content, making them a good choice for making

Figure 1: Freshly sliced Tomatoes (Kumar et al., 2017).

Figure 2: Roma tomatoes cultivated in Nigeria (Osaretin, 2021).

tomato powder. Hence, for this Design, ROMA TOMATOES will be our choice in producing tomato powder. Samples of typically available tomatoes are shown in (Figure 1).

As seen in (Figure 2), Roma tomatoes were used in this research. The raw tomatoes were obtained from Uchi Market, an open and commercial market in Auchi Town, Edo State. This was administered to keep up with the high capacity to be processed per day.

Process routes for tomatoes

There are various ways to produce tomato powder from raw tomatoes. The primary process is the dehydration process by which moisture was removed from the tomatoes. The universal routes taken in the production of tomato powder include choosing and sorting the tomato, washing and blanching. From the blanching process, there are different routes that plants can take to get tomato powder. For some processing plants, after the blanching process, the tomatoes are pulped to remove the solid particles within, then dried to obtain tomato powder. For other processing plants, the tomatoes are sliced after blanching, then dried, after which the dry tomato slices are milled to get tomato powder. The process routes taken by seven senior year Chemical engineering students in my research group included choosing and sorting the tomatoes, washing, blanching, grinding, drying, and

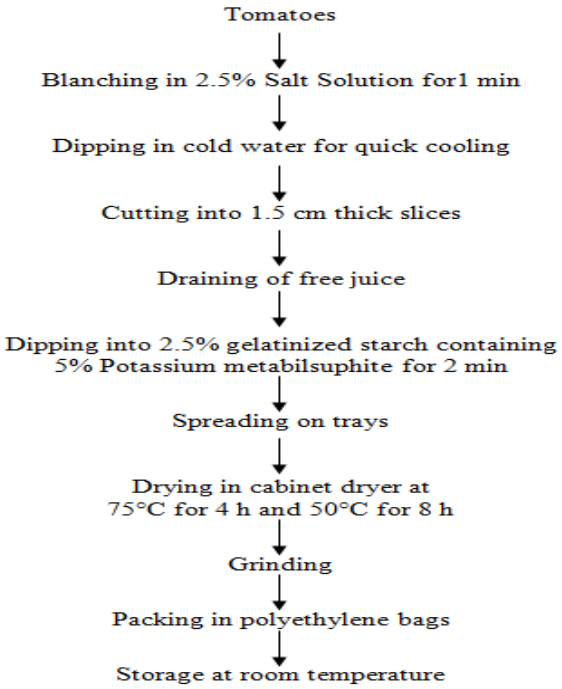

Figure 3: Tray drying process for tomato slices (Osaretin, 2021).

packaging the tomato powder. Grinding was picked over pulping so that all the solid particles would contribute to the yield of the tomato powder.

Dried tomato products

Tomatoes are perishable, but they can be dried to increase their value. To generate high-quality tomato powder, tomato slices can be dried in trays or tunnels, or tomato pulp can be sprayed (Cernîsev, 2010; Gaudel et al., 2022). Drying extends their availability all year. Dried tomato slices are a versatile component that may be utilized in a variety of dishes. After washing, good quality tomatoes are blanched in plain water or a 2.5 percent salt solution for 1 minute. Blanched tomatoes are swiftly immersed in cold water (Cernîsev, 2010; Liu et al., 2010; Osaretin, 2021). On perforated or aluminum trays, 1.5 cm thick slices are drained of surplus juice after nine minutes in 2.5 percent gelatinised starch with 5 percent potassium metabisulphite (Goula et al., 2006; Osaretin, 2021). They were dried in a tray dryer at 65-70 degrees Celsius until the moisture content was 4.5 percent. These slices might be polythene-wrapped or powdered (Figure 3).

Tomato powder

Tomato powder preparation is another method for storing tomato solids during the off-season and provides consumers with ease (Giovanelli et al., 2002; Osaretin, 2021). The powder can be utilized in the creation of other processed products such as culinary dishes, reconstituted into juice, or employed as a raw material in the production of secondary effects such as sauce, ketchup, and chutney (Anandharamakrishnan, 2020; Giovanelli et al., 2002).
Tomato powder can be manufactured through tray drying, foam mat drying, or spray drying. The powder obtained by various procedures differs in its qualities in addition to its color, nutrition, and reconstitution. Whole tomatoes are cleaned, washed, and allowed to lose surface moisture before being ground into tomato powder (Osaretin, 2021). Hot pulping procedures are used to extract juice, and pulp is filtered to obtain pulp-free juice, which is subsequently concentrated under a vacuum (Osaretin, 2021). The concentrated liquid is blended with a foaming ingredient to form a foam, which is subsequently dried with hot air. The dried powder is cooled, processed, and milled into a fine powder.

Figure 4 displays the spray drying process used to make tomato powder. Tomatoes with thick walls, brilliant red color, high solids, and high pectin concentration are ideal for dehydration (Osaretin, 2021).

Enzymatic treatment of the juice may also be used to improve the recovery of liquids, solids, and colors. Seeds and skin pieces are removed prior to particle size reduction (Liu et al., 2010; Osaretin, 2021). Using a vacuum pan or double effect evaporators, the juice is concentrated to the required total solids level. Maltodextrin (10% DE) and SiO2 (1%) are added to concentrated juice to improve the powder's color and rehydratability (Liu et al., 2010).
An atomization speed of 25,000 rpm and an inlet air

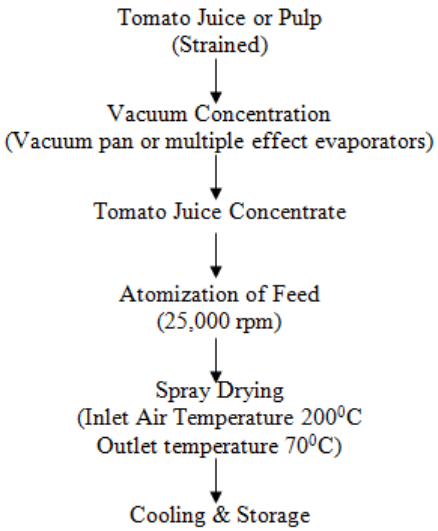

Figure 4: Spray drying process for the preparation of tomato powder (Goula and Adamopoulos, 2005).

temperature of 2,000 degrees Celsius are recommended for producing high-quality tomato powder (Liu et al., 2010; Osaretin, 2021). The lycopene content of tomato powder determines its color, which is affected by thermal processing.

Thermal damage and powder quality are thus determined by adjusting the feed rate, air intake and exit temperatures, additives, and atomization speed (Beecher, 1998; Osaretin, 2021). The powder can be packaged in oxygen and moisture-resistant films. It can also be vacuum-packed to increase its shelf life (Martins et al., 2020; Osaretin, 2021).

Drying Methods

Three types of drying methods are commonly being applied:

Hot air oven drying: Hot air oven drying Hot air drying process was performed using a dryer (Venticell –lsis, model number D 111004 /made in EU). Tomato slices were distributed uniformly as a thin layer onto the trays and dried at 55°C for 8 hours (Balladin and Headley, 1999).
Ghanem (2002) designed and manufactured solar drying the dryer on the roof of the Faculty of Agricultural Engineering - Al-Azhar University, Nasr City. Was used; the drying process was carried out at 40°C. This research had equally used a solar thermal drying system after blanching. The CAD diagram is shown the (Figures 5-6).
The Solar Thermal Chambers were field fabricated from acrylic and mild steel. They are built on the ground in two sections, the drying chamber and the frame and tray from mild steel angle bar (Figure 6) and stainless-steel sheets.

Spray drying

Spray drying produces dry powder from a liquid or slurry by rapidly drying with a hot gas. This is the preferred method of drying foods or pharmaceuticals. Air is the heated drying medium. Parameters like juice concentration, addends, feed flow rate, and the inlet and outlet air temperatures have a significant role in the yield of Fruit powders. Fruit powder is hygroscopic and requires drying agents.
Despite its high capital and installation costs, reduced thermal efficiency, and susceptibility to heat degradation, the spray drying method has the following advantages over other forms of drying (Osaretin, 2021):

- Low labour cost
- Relatively simple operation and maintenance
- Reduces the transport weight of foods
- Compliance with the product standards.
- Continuous and easy to control the process
- Applicable to both heat-sensitive and heat resistant materials
- Satisfies aseptic/hygienic drying conditions

METHODOLOGY

Fabrication of the Novel Semi-Automatic Machine

The materials used include; mild steel, stainless steel, plastic, angle bars and k- type thermocouples. Machine fabrication consists of various techniques such as lathe machining, drilling, boring, slotting, oxyacetylene gas

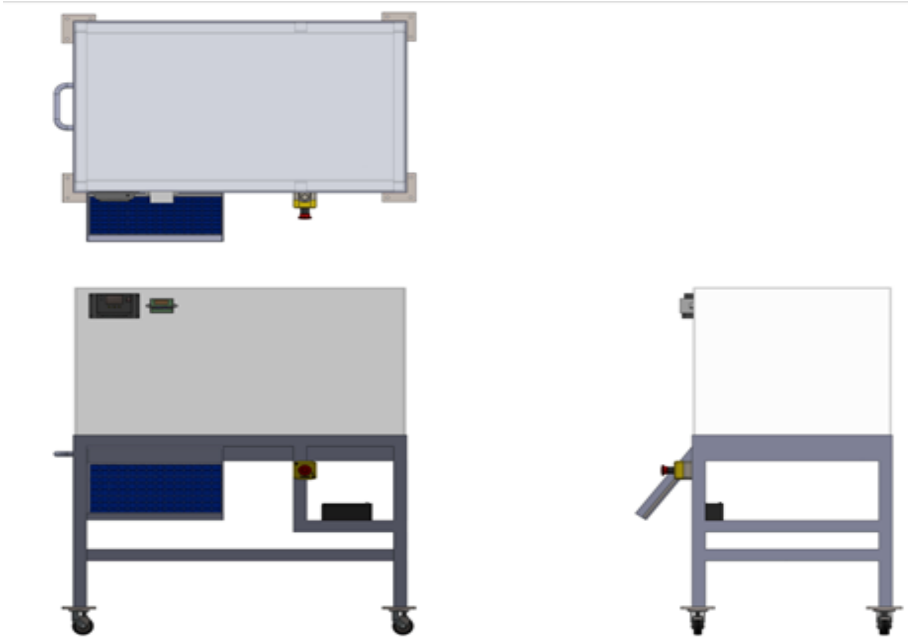

Figure 5: The CAD diagram novel solar thermal dryer.

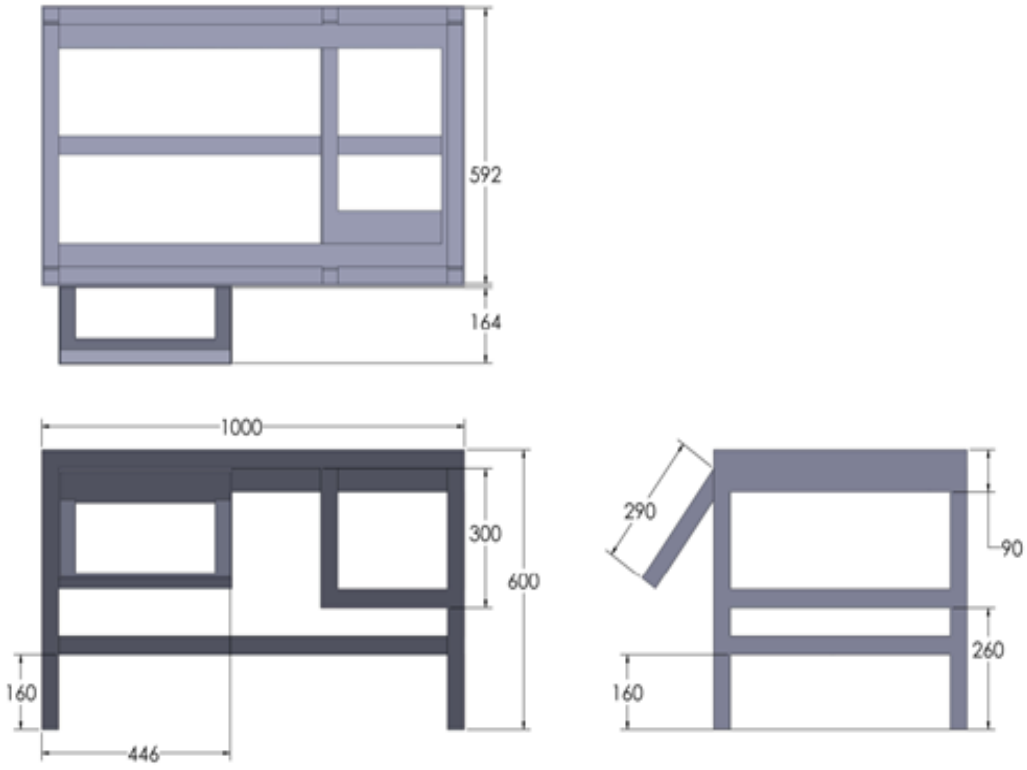

Figure 6: The CAD diagram of the frame for novel solar thermal dryer.

welding, grinding, and electric welds. The machine's schematic is shown in Figures 5-8. Accessibility and ease of assembly were critical considerations throughout the creation of this model. Parts are carefully connected thoughtfully. When selecting engineering materials, many factors must be considered, but high temperature, strength, and corrosion resistance are typically the most important for a food processing machine. Stainless steel

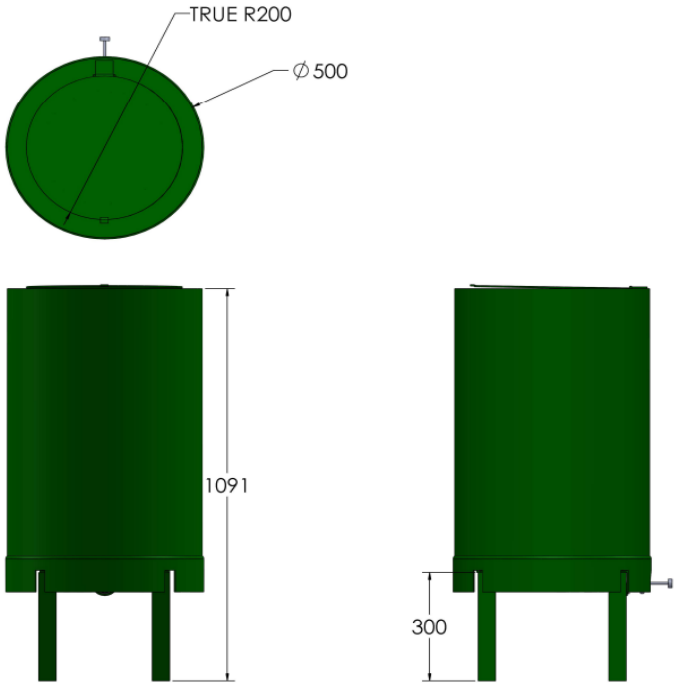

Figure 7: CAD diagram of the tomatoes blanching machine

and mild steel are the optimal construction materials for the tray dryer used in tomato powder manufacturing due to their superior properties. Possesses characteristics such as high corrosion resistance, a suitable modulus of elasticity, ease of fabrication, standard sizing, and a favourable relative costing rate(Osaretin, 2021). To impart corrosion resistance, the chromium content must be more significant than 12 percent, and the greater the chromium content, the greater the alloy's resistance to corrosion under oxidising conditions. The addition of nickel enhances the corrosion resistance in non-oxidising environments. Stainless steel (SUS 304 stainless steel) and mild steel were used to fabricate the parts of the machine.

The blanching machine

Blanching, or Boiler, is used in scalding vegetables or fruits in hot water or steam to reduce the enzyme action, which causes a change in colour, texture, and loss of flavour. Blanching cleanses the surface of dirt and organisms, brightens the colour and helps retard the loss of vitamins(Osaretin, 2021). This machine was fabricated using a mild steel sheet and stainless-steel plates. The CAD diagram of the Boiler is shown in (Figure 7). A water blancher is made up of a pan that has inlet and outlet ends. Several outlets are linked to the pan's bottom (Osaretin, 2021). The water is returned to the pan via injectors by the circulation system. Directly injected steam or a heat exchanger heats the water. Hot water blanching of ripe tomatoes at 60^{o}C for one minute is the most efficient pre-treatment for keeping the red color of the dehydrated product, according to Research and Development Centres in Anuradhapura, Sri Lanka. As a result, this will be the condition of the process (Osaretin, 2021).

Grinding machine

Grinding is when the natural liquid, vitamins, and minerals are extracted from raw fruits. This process strips away any solid matter from the fruit and what is left is liquid only. Grinding is vital for food manufacturers so that products are the same every time; consistency is critical. If a recipe is not blended correctly, the final product's taste, texture, colour, and appearance can all be affected. The grinding machine was made from mild steel and aluminium (Figure 8).

RESULTS AND DISCUSSION

The drying rate curve for the tomato slices from solar drier thermal drying at 38.5 °C is shown in Fig. 10. The moisture content of tomatoes was reduced from an initial level of 93.91 to 28.9% in 3 to 4 days of solar thermal drying (Figure 9). It was observed that the samples dried had a deformed texture with noticeable shrinkage and hardened,

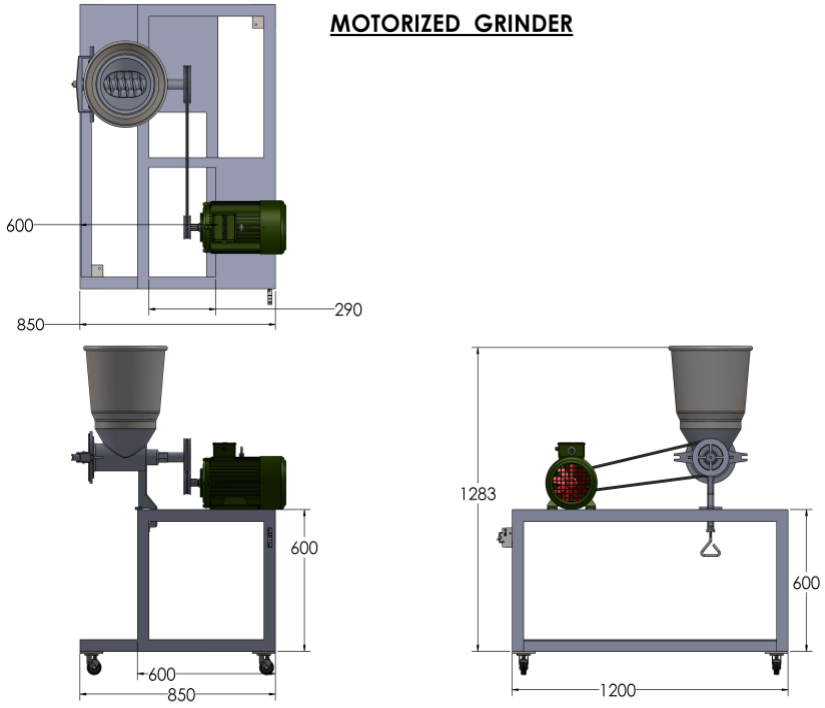

Figure 8: CAD diagram of the tomatoes grinding machine.

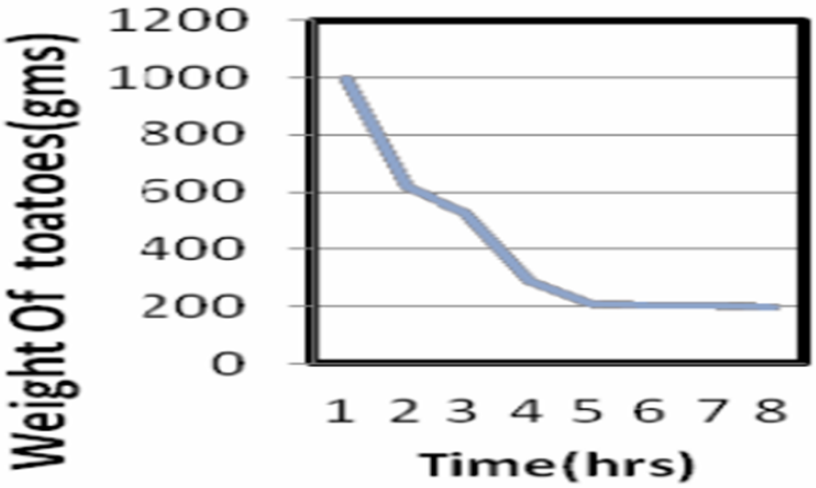

Figure 9: Effects of the solar thermal drying method on moisture content

especially toward the end of the drying period. Further tests and evaluations need to be carried out on the entire system, from washing and blanching through packaging.

Conclusion

While designing a pilot-scale powdered tomatoes production machine, the design and system layout were needed as a baseline to decide how this machine would operate and if it was feasible. The advantages of a plant and process route in terms of the ability to control outputs and optimise yields remain and should be investigated further in future iterations of the project. A potential implementation pathway would be through a community-based powdered tomatoes production unit, with operators rotating and feedstock collection among the various community members. This kind of novel system could

allow for more electricity and energy by-product production; which as rural communities continue moving up the energy ladder will become increasingly important. However, a large-scale system would have to be designed for a more specific production capacity to internalize the benefits of a more complex control unit. The Design and testing performed as part of this paper have provided an essential step toward deploying such novel production units for application in rural communities in Nigeria. Different drying techniques have been used for the drying of tomato slices. Compared to other samples, solar thermal drying of tomato slices has been tested for desirable texture, colour retention, and quality. Moisture content was reduced from 93.91 to 28.9% in 3 to 4 days, with a bit of alteration in texture. Further tests on acidity and other sensory evaluation need to be carried out.

Author Contributions

Conceptualisation of Design, Suleiman I.A; Methodology, Suleiman I.A. Rafat Abubakar Seghosimeh, Oladebeye Aderonke Adenike; Testing and assessment Engr. Suleiman I.A., Dr. Rafat Abubakar Seghosimeh; Writing original draft Suleiman I.A; Review and editing Suleiman I.A.

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