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Development of an integrated grating and slicing machine for starchy vegetables

Chung Yee Lok [1], M. K. Siti Mazlina [1]* and B. T. Hang Tuah [2]

*[1] Department of Process and Food Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia. [2] Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia. *e-mail: siti@eng.upm.edu.my*

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Abstract

Processed foods usually undergo one or several unit food processing operations before becoming the final products. Many food processing equipments were developed to perform more than one operation in food processing by providing practical purposes that further enhance their performance. However, conventional processes of grating and slicing that produce grated and sliced food products normally involved two units of independent operation machines. Therefore in this study, grating and slicing processes have been combined into a single operation through an integrated machine for simultaneous grating and slicing operations. The purpose of integrating both grating and slicing processes is to increase productivity through the reduction of cost, time and the number of unit operations, which are involved in the processing system of grating and slicing production. The machine's design specifications were identified to ensure that simultaneous grating and slicing operations in an integrated machine are capable to process the raw materials (starchy vegetables) simultaneously for grated and sliced outputs. A final machine design was generated by following a product development process as the research method. The design process steps starts from planning, concept development, detail design and machine fabrication, testing and refinement. The final design of the machine (at present) shows that it is suitable for use in industrial processing level which the output rate is powered at 750 W with variable speed of 0 – 180 rpm, grated and sliced production range of 750 – 1200 kg/h and 250 – 400 kg/h, respectively. This newly designed machine is easy to setup, handle, store, clean, service and maintain. The design of an integrated grating and slicing machine will express a better understanding on the machine capability to reduce cost and energy for simultaneous grating and slicing processes with increased productivity.

Key words: Grater, integrated, machine design, slicer, starchy vegetables.

Introduction

Most agricultural products cannot be consumed directly but can be supplied as raw materials for subsequent food processing operations. The quality of these processed food products are significantly affected by the processing equipment [1]. Due to the diversity of food processes and food products, several specialized unit operations are being developed in the food processing industry [2]. Therefore, various food processing equipments are available in the market, ranging from small to large-scale machines.

Processed foods usually undergo one or several units of food processing operations before becoming the final products. Modern technologies can produce a more specialized and technically advanced apparatus that performs multi-unit operation of food processing [2]. These machines were designed with the purpose of providing practical inventions that further enhance their performance, including higher drive capabilities for better quality food products.

There are various vegetable grating and slicing machines in the current market, which vary from manual, semi-automatic, to fully automatic types. However, these machines are in a single-unit operation only. Domestic and industrial consumers nowadays prefer either semi-automatic or fully automatic type of vegetable grating and slicing machines since they are easier to be used for shorter production time with more hygienic process, user friendly operation, and lesser energy utilization.

Consumers need to purchase two separate single-unit operation vegetable grating and slicing machines in order to meet both grating and slicing purposes; thus, doubling the cost. From literature and patent search, there was a single unit operation of grating and slicing devices for kitchen appliances or light duty machines that operate in single unit operation with interchangeable cutting blades but not in integrated unit operation. The machine is a single-unit operation vegetable preparation machine [3]. The machine can produce grated and sliced vegetables in a single-unit operation with changeable or fixed type of grater and slicer accessories. However, the machine is unable to perform both simultaneous grating and slicing operation. Besides, the machine has no variable speed controller of two choices of fixed speed. Hence, this research aims to solve the current problem by combining both grating and slicing applications in an integrated vegetable grating and slicing machine that increases productivity with lower cost and space utilization.

In tropical regions, starchy vegetables are important food supplying the energy needs of many populations [4]. This research is focused on the study of starchy vegetable types primarily of starchy roots and tubers. White potato and yam are the major starchy vegetable tuber crops, while sweet potato and tapioca are the principle of starchy vegetable root crops. White potato is the selected starchy vegetable since potato fries is one of the most

popular products in many countries. Fried potato is famous for its appealing, flavour and aroma [5]. The texture of fried potato is mainly depending on the quality of the raw material [6]. The food materials will undergo physico-chemical changes since frying affects textural and structural properties [7]. Another common snack in Asia is fried sweet potato chip and its consumption is increasing [8]. Tapioca and yam are reliable sources of dietary energy and important crops in tropical countries. Therefore, in this study, four types of starchy vegetables tested were white potato, sweet potato, tapioca and yam.

Starchy vegetables are harder in texture and of higher demand in market than non starchy vegetables, thus this research focused on designing an integrated grating and slicing machine for starchy vegetables that could fulfill the needs of food processing industry. The design of the machine is to cater the production of grated and sliced products that are mainly used as food chips and finger products.

Materials and Methods

Development process of an integrated grating and slicing machine for starchy vegetable: The product development process generally follows a well-organized structure and systematic flow of activities [9]. A product design is the result of a methodical development effort with well defined product specifications and project goals. The product development process flow for this research is shown in Fig. 1.

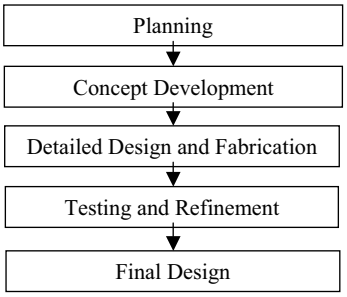


Figure 1. New machine development process.

Planning design: The task was to design a new machine that integrates the grating and slicing process for starchy vegetable products. The research attempted to identify and verify the initial operation unit of preparing raw vegetables as grated and sliced products from the prototype machine operation, and also attempted to verify the prototype machine that is capable of simultaneous grating and slicing process. The requirement of the research for the development of prototype machine was to satisfy the overall machine practicality in both simultaneous grating and slicing processes. The next requirement is to fabricate and test the prototype machine.

Conceptual design: Development of an integrated grating and slicing machine (also known as integrated machine from now on) was completely a new approach of design concept in vegetable preparation at industrial processing level. The integrated feature was the first design idea to position both grater and slicer for simultaneous operation. Table 1 shows the target design specifications of an integrated machine. It shows that vegetable is produced in size reduction form by mechanical method with mechanical cutting blades of grater and slicer. The mechanically driven components involved in the processes are the connected power supply units, drive motors, shafts, bearings, grater, and slicer.

The development of the machine's equipment and the operational research: In the development of this machine, three important steps were established. First is the detailed design, second the machine fabrication, and finally the operational analysis of the fabricated machine.

Detailed design: Prior to detail design, many comparisons between the single unit of grating and slicing have been made. Table 2 shows the summary of some existing single unit operation for grating and Table 3 shows slicing appliances. Tables 2 and 3 also show the related single unit operation of grating and slicing devices for kitchen appliances or light duty machines. To-date, lack of integrated unit operation of grating and slicing devices has been particularly designed for industry purposes. There is a closely related machine that is built as a single unit operation industrial machine for heavy duty task [3]. The machine can produce many types of grated and sliced vegetables in a single unit operation with changeable or fixed type of grater and slicer accessories. However, the machine is unable to perform both simultaneous grating and slicing operation because of its single-unit operation. Besides, the machine has no variable speed controller but there are two choices of fixed speed selector.

In this study, the new design of the integrated machine was developed as illustrated in Fig. 2. The target performance of this machine is to double the performance, where it could perform grating and slicing simultaneously and have variable speed range.

The fabricated structure of the machine: Fig. 3 shows the final fabrication of the prototype machine. It contains machine body frame of top cover, upper casing, and lower casing which allow easy assembly and setup of the integrated machine. In addition, handles and brackets were also welded onto the machine body frame for handling and locking purposes. The major mechanical components and electric motor are safely secured inside the lower casing provided space. The dimension of the machine body frame was slightly customized, as well as four casters were installed for the machine's mobility (500 mm length x 350 mm width x 800 mm height).

Operational analysis: Prior to operate the newly design machine, the raw materials were prepared. These were sourced locally and in fresh and fine condition.

Table 1. Design specifications of an integrated grating and slicing machine for starchy vegetables.

Mechanical Operation	Mechanical Method	Mechanical Cutting Blade	Mechanical Driven Components	Mechanical Function
Grating	Size reduction method	Grater	Connecting power supply units, drive motor, shafts, bearings, and grater	Grate raw starchy vegetables into grated output
Slicing	Size reduction method	Slicer	Connecting power supply units, drive motor, shafts, bearings, and slicer	Slice raw starchy vegetables into sliced output

Table 2. Summary of some existing single unit operations of grating equipment.

Patent Publication Number and Title	Brief Description of the Invention	Applications
WO 97/29641 A1 Rotary Grater[10]	This invention relates to an improved hand-held, hand-crank operated, drum-type grater for grating cheese and similar food products.	Kitchen appliance and for domestic use
WO 99/17649 A1 A grater[11]	This invention relates to a grating appliance that consists of a container for grating food products.	Kitchen appliance and for domestic use
CA 2637160 A1 Cheese grater[12]	This invention relates to a manually operated grater for grating hard cheese in grated, shredded, or flaked form.	Kitchen appliance and for domestic use
CA 2578500 A1 Food grater[13]	This invention relates to a grating appliance for holding and grating food products.	Kitchen appliance and for domestic use
CA 2599744 A1 Multi grater[14]	This invention relates to a multi grating appliance for cheese and similar food products.	Kitchen appliance and for domestic use

Table 3. Summary of some existing single unit operations of slicing appliances.

Patent Publication Number and Title	Brief Description of the Invention	Applications
WO 02/19831 A2 Butterfly Chop Slicer [15]	This invention relates to a meat slicer for multiple slicing of boneless meat.	Kitchen appliance and for domestic use
WO 01/87551 A2 Slicer with Unitary Handle[16]	This invention relates to a slicer that consists of a slicer body with rotatable blade for slicing food products.	Kitchen appliance and for domestic use
WO 2008/154674 A1 Slicing Device[17]	This invention relates to a device that consists of a container for slicing cheese and similar food products.	Kitchen appliance and for domestic use
WO 2004/091872 A1 Produce Slicer[18]	This invention relates to a produce slicer that consists of both radial and auxiliary cutting blades for slicing food products in wedges form.	Kitchen appliance and for domestic use
CA 1115181 A1 Slicer for Food Products [19]	This invention relates to a slicer for slicing cheese and similar food products.	Kitchen appliance and for domestic use

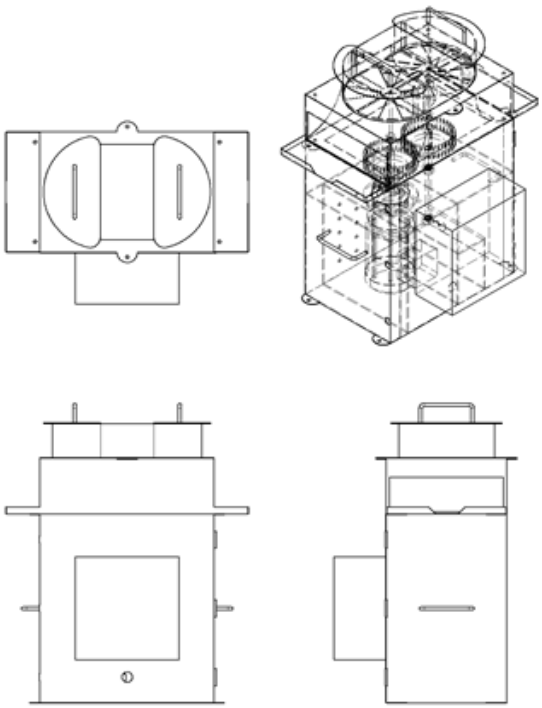


Figure 2. Multi-view diagram of an integrated grating and slicing machine for starchy vegetables.

Figure 3. Fabrication of the prototype machine.

The processing operation begun by supplying the starchy vegetables into the space in the top cover. Then, the presser was used to press the supplied starchy vegetables into the grating and slicing processes. As a final point, the grated and sliced extracts can be collected at the space in the upper casing. The integrated machine is power-driven by switching on the power supply of 240 V. For cleaning purpose, the top cover is first to be removed. Then, the upper casing (extraction collector) can be removed for cleaning process. The lower casing incorporated with a casing door is easy to recognize and practical for machine service and maintenance. The processing operation is easy to be distinguished and executed.

The criteria for testing and validation were outlined for the prototype machine as shown in Table 4. These criteria were

Table 4. Testing and validation criteria of the prototype machine.

Testing Criteria	Validation Criteria
Functionality	Capable to grate and slice simultaneously for double production efficiency
Maintainability	Easy to store, clean, service, and maintain
Convenience	Easy to handle, transport, assemble, and setup
Robustness	Well-built and stable
Manufacturability	Use of cost-effective standard parts and materials

selected because it links with the performance, reliability, usability and manufacturability of the prototype machine design.

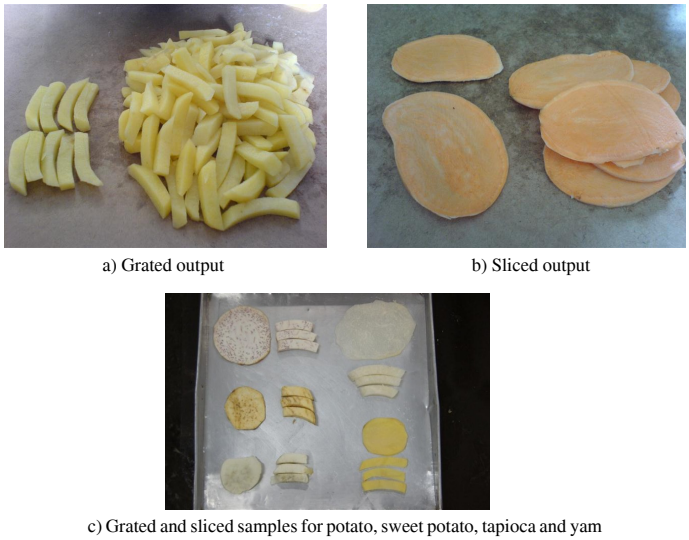
Results and Discussion

Table 5 shows the final design and comparison data of the integrated machine designed with a broader range of grating and slicing, i. e. 750-1200 kg/h and 250–400 kg/h, respectively. The power used for the machine is considered low, and another advantage is variable speed rather than fixed speed. Table 6 shows the main benefits of integrated unit operation. The integrated machine provides better performance and efficiency since it can work simultaneously for grating and slicing processes compared to single unit machine. Thus, the design of an integrated machine will provide a new engineering solution that promotes both simultaneous grating and slicing. This will lead to double production efficiency with faster production rate, as well as lower cost and space consumed.

The integrated machine was specifically designed with the best sharpness of vegetable processing blade, and the blade was critically dimensioned in order to cut and prepare the vegetables with optimal quality. Fig. 4 illustrates the grated and sliced outputs from the machine. Verification on the consistency of the product size was also done by measuring each of the sample outputs. The output products could be considered as fine quality and suitable for subsequent process, such as frying.

Fig. 5 illustrates the grated French fries (10 mm x 10 mm square section) and sliced chip (2 mm thickness) of potato output with optimal quality after modification of the machine design.

The functionality and operational of the newly designed and fabricated machine was tested. Table 7 shows the verification checklist of the prototype machine. The verification checklist



a) Grated output b) Sliced output

c) Grated and sliced samples for potato, sweet potato, tapioca and yam

Figure 4. Grated and sliced outputs of the machine design.

Figure 5. Grated French fries and sliced chip of potato output with optimal quality after modification of the machine design.

shows that the machine is capable to grate and slice starchy vegetables. The inclusion of this machine in the food processing plant could improve the productivity through the reduced number of unit operations and also reduced processing time.

Table 8 shows the finalized design specifications of an integrated grating and slicing machine for starchy vegetables.

Conclusions

An integrated machine for grating and slicing was successfully designed, fabricated and tested. The unit was tested and found capable to grate and slice starchy vegetables simultaneously. This integrated machine is developed specifically for industrial intention of grating and slicing vegetables to produce grated and sliced extracts in a single machine operation. At present state, the machine is already leading towards greater improvement in production

Table 5. Design and comparison data of the integrated machine for vegetable grating and slicing.

Machine unit operation	Performance	Range of production pate (kg/h)		Power (W)	Speed (RPM)
		Grated product	Sliced product		
Conventional single-unit	Single	700 – 900	300 – 420	550	375 and 750 (Fixed speed)
Integrated-unit	Double	750 – 1200	250 – 400	750	0 – 180 (Variable speed)

Table 6. Main benefits for integrated-unit operation machine.

Machine Unit Operation	Application Target	Processing Capacity	Variety of Cuts	Simple and Sturdy Design	Induction Motor for Intensive Use
An integrated-unit operation	Industrial machine for heavy-duty machinery task	Large hopper that allows bulky vegetables to be processed	Comprehensive range of grater and slicer to cut and prepare the vegetables with optimum and precision qualities	All parts that are in contact with foodstuffs can be easily removed for cleaning, so that it maintains high standards of hygiene	Heavy duty commercial asynchronous motor assures for longer life machinery, reliability, silent process, extra power, less vibration and no maintenance

Table 7. Verification checklist of the prototype machine.

Testing Criteria	Validation Criteria	Verification
Functionality	Capable to grate and slice simultaneously for double production efficiency	Verified
Maintainability	Easy to store, clean, service, and maintain	Verified
Convenience	Easy to handle, transport, assemble, and setup	Verified
Robustness	Well-built and stable	Verified
Manufacturability	Use of cost-effective standard parts and materials	Verified
To verify the customers' needs have been met	Identifying customer needs that request for both simultaneous grating and slicing proposes that save cost and space (compact machine size)	Verified
To assess the market potential of the product	It is capable to produce simultaneously grated and sliced outputs for starchy vegetables with optimal quality, but also lead for great increase in double production efficiency (works simultaneously for grating and slicing)	Verified

Table 8. Final design specifications of an integrated grating and slicing machine for starchy vegetables.

Mechanical Operation	Mechanical Method	Mechanical Function	Mechanical Design Specifications
Simultaneous grating and slicing	Size reduction method	Simultaneously grate and slice for raw starchy vegetables into grated and sliced outputs of optimal quality in double production efficiency with faster production rate, low cost and space consumed as well as reduced production waste	1. Connecting power supply units, drive motor, shafts, bearings, grater and slicer 2. Three-phase induction motor with reduction gear 3. Single-phase to three-phase 4. Compact machine size, assembled with overlapping arrangement of the grater and slicer 5. Portable machine, installed with four casters

efficiency and output rate with lower utilisation cost and space consumption. Besides, this integrated machine is easy to handle and consumes lesser workforce and operational time. The integrated machine is also capable of simultaneously producing grated and sliced outputs for starchy vegetables with optimum and precision quality. This prototype machine design also provides a structured awareness and reference for future research on potential innovations in integrated food design and process in terms of capacity (higher output rate in kg/hr), variable speed control (different selection range of variable speed), power consumption (W), and space utilization (compact-sized machine).

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