

# **Bachelor thesis**

**A time - motion study of the production process and areas  
to be optimized at an *Agaricus bisporus* farm**

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## ABSTRACT

Despite the challenges in food production during the Covid-19 pandemic, there has been a constant demand for champignons in Germany. With the need of improving production levels, a study was conducted at an *Agaricus bisporus* farm located in Geldern, Germany. The farm has two sites (A/B) which follow the traditional system of harvesting, and another site (site C) which follows a technically advanced work simplification approach. Time-motion studies were carried out to determine the most time-consuming activities and the areas that needed to be improved. The continuous sample method was chosen over work sampling in this study because picker and packer tasks (at site C) were frequent. Subsequently picking efficiencies of the farm were found by empirical data collection. Finally, strategies for improving production rates were created and prioritized using a SWOT analysis in conjunction with the Internal Factors Evaluation Matrix (IFEM), External Factors Evaluation Matrix (EFEM) and Quantitative Strategic Planning Matrix (QSPM). Significant results were obtained at sites A/B after changes in the logistics within the production process, with picking efficiency increasing from 39% to 43%. Technical issues at site C were significantly reduced after recipe settings were changed, and picking efficiency increased from 49 percent to 54 percent. The strategy with the highest priority level from the IFEM, EFEM, SWOT, and QSPM analysis was analyzing the pickers' performance over time. Undoubtedly, further research is a driving force behind the development of novel harvesting technologies in this field of agriculture.

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## LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AS	Attractiveness Score
DA	Data Analysis
DR	Data Recording
EFEM	External Factors Evaluation Matrix
ES	Empirical Setting
IFEM	Internal Factors Evaluation Matrix
INT	Intervention
OBS	Observer
PESTLE	Political, Economic, Social, Technological, Legal and Environmental
QSPM	Quantitative Strategic Planning Matrix
RD	Research Design
RPZ	Rheinische Pilz Zentrale
SD	Standard Deviation
SE	Task Category
SPACE	Strategic Position And Action Evaluation
SS	Suggested Strategies
STAMP	Suggested Time And Motion Procedures
STAS	Sum of Total Attractiveness Scores
SUB	Subject
SWOT	Strengths-Weaknesses-Opportunities-Threats
TAS	Total Attractiveness Score

TC

Task Category

TMS

Time Motion Studies



# 1 INTRODUCTION

Global mushroom output has increased not only due to the growth of the world population, but also due to the increase of the per capita consumption (Royse, 2014, EDA, 2018). Looking into the statistics, over a 15-year period (from 1997 - 2012), the global per capita consumption has risen from 1 kg/ year to more than 4 kg/year (Royse, 2014), where China and the United States being the largest producers in the world (Raut, 2019). The perceived healthiness of mushrooms (due to diversity of minerals, vitamins, and low calorie content – particularly in fresh produce), as well as the expanding vegetarian and vegan trend among Germans, are considered to be the major factors driving per capita consumption rise in Germany (EDA, 2018, BDC, 2015). As a result, fresh mushrooms i.e., white, and brown champignons, chanterelles, oyster, and porcini are high in demand (BDC, 2017). According to the Mushroomforum (2021), despite the challenges posed by the Covid-19 pandemic in terms of labor and restaurant closures, which could theoretically lead to a decrease in market demand, German mushroom production in 2020 has been 6200 tons higher than in 2019, and 2021 (Van Dieten, 2021a) indicating that consumer demand has risen despite the challenges.

Although there are over 2000 types of mushrooms in nature, only about 22 are intensively farmed for commercial purposes (Manzi et al., 2001), with *Agaricus bisporus* being the most widely cultivated in the world (Atila et al., 2021, Sánchez, 2004). They are commonly grown on shelves, foil bags or containers (Horgoş et al., 2012). Generally, *A.bisporus* (champignons) are composed of 85 - 90 % of water, where this percentage greatly varies upon the relative humidity and

temperature given during the growing phase (Dhamodharan and Mirunalini, 2010). Champignons are supposed to be an excellent source of some essential amino acids, minerals, and vitamins i.e., vitamin B2, B5 and B3 (El Sebaaly et al., 2019). Further, they contain carbohydrates, crude proteins, fats, sugars, proteins, and iron (Ying, 1987). Several studies have found out that *A. bisporus* consumption can be beneficial in gastrointestinal health, metabolic syndromes, cancers and on improving the vitamin D levels of individuals (Blumfield et al., 2020, Wani et al., 2010, Dhamodharan and Mirunalini, 2010).

It is found out that edible mushrooms are a highly tradable commodity due to their short growing periods, minimal input requirements and simple production procedures (Rosmiza et al., 2016, Shivute, 2020). Further, the minimal land requirements and richness of spent agricultural residues (which can be used in mushroom cultivation) makes it an attractive industry in the world where food and financial insecurity are current prominent issues (Higgins et al., 2017). But it should be noted that it also requires suitable substrate and quality spawns (Thiribhuvanamala et al., 2012, Foley and Yakushenko, n.d), good harvesting techniques, packaging and storage in order to improve the yields and to have quality productions (Foley and Yakushenko, n.d).

This thesis has been based on the production process of a large scale *Agaricus bisporus* farm in Germany, and the objectives of this study were as follows.

- I. Finding out the picking efficiencies of sites A/B and C of the farm.
- II. To identify the areas that could be optimized within the production system by conducting a Time Motion Study (TMS).

- III. To suggest strategies on how to optimize the productions further by an Internal Factor Evaluation Matrix (IFEM), External Factor Evaluation Matrix (EFEM), SWOT (Strengths-Weaknesses-Opportunities-Threats) analysis and a Quantitative Strategic Planning matrix (QSPM).

A literature survey (referred as “state of knowledge”) was done to study the existing theories and concepts in the areas of work simplification, time-motion studies, IFEM, EFEM, SWOT analysis and QSPM in strategic management, to formulate the background for this research and to find out how to applicable they are in the real-world context.

## 2 MATERIALS AND METHODS

### 2.1 Data for the *state of knowledge*

Tools used to gather sources for the literature survey were Google Scholar, ResearchGate, ScienceDirect and Elsevier. The literature research was done in the areas of “work simplification”, “scientific management”, “time-motion studies”, “QSPM” and “SWOT analysis” from 01.10.2021 – 01.12.2021. Key terms used for the search were, “empirical data collection methods”, “time and motion studies in agriculture”, “methods of time -motion studies”, “stopwatch time studies”, “work simplification in agriculture”, “automation of mushroom harvesting”, “mushrooms cultivation and robotics”, “SWOT analysis in agriculture”, “limitations and advantages of SOWT”, “SWOT and QSPM matrix in strategic management” and “rating systems for EFEM and IFEM”.

### 2.2 Empirical data collection

#### 2.2.1 Data collection site

Data for the empirical study were collected from a large scale *Agaricus bisporus* farm called Rheinische Pilz Zentrale (RPZ) located in Pont, Geldern, Germany from May – September 2021. Sites A and B which grow white *A. bisporus* (strain 737) consist of 24 growing halls of size 1296 m<sup>2</sup> each and site C has 18 growing halls of size 756 m<sup>2</sup> each, and they grow a brown strain of *A. bisporus* (Heirloom). Sites A and B harvest and sort champignons in the traditional way while site C has a technically advanced system for this process.

### 2.2.2 Time - motion study for activities other than picking

A time-motion study was conducted to determine the average time required for each activity performed during working hours other than picking. The results were analyzed, and decisions were made about which areas needed improvement to increase the farm's picking efficiency. A TMS was performed again after the improvements were made, to see if there was a significant improvement in those areas.

The time taken for each activity during the observation time of the picker (at sites A/B) and a packer (at site C) was recorded using a stopwatch and noted down. The stopwatch was allowed to run continuously throughout the observation period, and the time taken to complete each activity was obtained by subtracting the reading of the stopwatch at the beginning by the time recorded when the task was completed (continuous sampling method) as explained by Lowery et al. (1940) and Lopetegui et al. (2014). STAMP (Suggested Time and Motion Procedures ) method introduced by Zheng et al. (2011) was followed in planning this TMS to some extent. Twenty-six pickers were observed for 1 hour each before and after making improvements in the management at sites A/B. At site C, 20 packers were observed for 1 hour each, before and after making technical improvements and changes in the growing. 20 pickers at site C were randomly observed to find out reasonings for some of the results.

### 2.2.3 Average weights of (*A. bisporus*) champignons

Five mushrooms that were ready to be sent for packaging of each class (30 mm, 40 mm, 60 mm, 60 + mm, and canning quality) were randomly selected. These were weighed using a 4-digit scientific scale throughout both harvesting periods (also referred to as 1<sup>st</sup> and 2<sup>nd</sup> flush), and an average weight per champignon, per size class, was obtained (APPENDIX A and APPENDIX B). For this, 10 growing rooms at sites A/B and 10 growing rooms at site C were selected.

This was done to find out the average weight of a white and a brown champignon regardless of the size class to calculate the picking efficiency of the farm (section 2.2.5). The total number of mushrooms harvested during a flush was found out by dividing the total kilos of champignons harvested per size class (data obtained from the database “Sofi-He”) by the average weight of a champignon which was found out per size class.

Finally, the total kilos of champignons harvested during the flush (data obtained from the database “Sofi-He”) was then divided by the total number of mushrooms harvested, and average weights of champignons regardless of size class was obtained (APPENDIX C and APPENDIX D).

### 2.2.4 Pick rate (champignons/minute)

#### 2.2.4.1 *By observation*

The pick rate was found out by counting the number of mushrooms picked for 5 minutes such that they were not engaged in any other activity but only picking. Picking time was regarded as the time taken to pick the champignon, making the decision about the quality and size, and placing it in the suitable punnet. Each

picker was observed during the first and the second flush and the average mushrooms harvested per minute was found out. The total population size ( $N_1$ ) at sites A/B was 78, the randomly selected sample size ( $n_1$ ) was 26. At site C, 20 teams ( $n_2$ ) (a team consists of a picker and a packer) were observed out of 30 teams ( $N_2$ ) in total.

#### 2.2.4.2 *By the database*

The actual pick rates were obtained by using data (total kilos of champignons harvested and the total hours worked) from the database “Sofi-He”. The total number of champignons harvested (found out as explained in section 2.2.3) was divided by the total working hours. The total hours worked includes the time for all activities done during the working hours i.e., picking, measuring, time consumed due to technical problems, crate changes, etc.

#### 2.2.5 Picking efficiency of the farm

Picking efficiencies were found out for sites A/B and site C separately. The picks (champignons) per minute by the actual data from the database (explained in section 2.2.4.2) was expressed as a percentage of picks (champignons) per minute by observation (found out as explained in section 2.2.4.1). For this, 15 growing halls were considered during their 1<sup>st</sup> flush and 2<sup>nd</sup> flush for each site (A/B and C).

*Picking efficiency (%)*

$$= \frac{\text{Pick rate by database (champignons per minute)}}{\text{Pick rate by observation (champignons per minute)}} \times 100$$

### 2.2.6 Statistical analysis

The averages and standard deviations (SD) were calculated for the weights of the champignons per size class. The standard errors (SE) were found out for the average weights of champignons regardless of size class. Furthermore, data from the time-motion study were evaluated for normality using the Shapiro-Wilk test by Shapiro and Wilk (1965). Thereafter, parametric (paired students t. test) or non-parametric test (Wilcoxon signed rank test) was performed according to the normality of the data. These results were calculated using RStudio version 1.2.5019, which is a supporting software for the R software (R Core Team, 2019). Graphs were created by downloading the package ggplot2 by Wickham (2016). Data were considered as normally distributed in the Shapiro-wilk test if the p values were greater than 0.05. If p was less than 0.05, the data was considered as not normally distributed. If the paired students t. test or the Wilcoxon signed rank test results gave a p value less than 0.05, then the results were considered as significant. Any p value greater than 0.05 were considered as not significant.

### 2.3 Data for the IFEM, EFEM, SWOT analysis and QSPM

Data for this study were gathered by the TMS (from April – September 2021), direct observation of the processes, and informal interviews with the farm manager, growers, and supervisors during October 2021. The farm manager and a growing manager were asked to rate and give weights for the internal and external factors brought up for the analysis and to give the ratings for the suggested strategies in the QSPM. Data analysis techniques used in this study were,



- i. Designing the IFEM and EFEM (input stage).
- ii. Analyzing the SWOT and developing the “suggested” (alternative) strategies (matching stage).
- iii. Designing the QSPM (decision stage).

## 3 RESULTS

### 3.1 State of knowledge

#### 3.1.1 Work simplification and scientific management

##### 3.1.1.1 *Basic concepts of work simplification and scientific management*

Work simplification as introduced by Hardin (1947) is working in an easier and a better way, instead of trying to work faster or harder. The efficiencies in the agricultural productions can be greatly improved, such as by making rational decisions in what tasks need to be done and how to do them (Young and Hardin, 1943). Fedrick Taylor (1856–1915), known as the father of scientific management has identified that the greatest loss by work inefficiencies is not material rather human effort (Lopetegui et al., 2014). Therefore, he has made efforts in introducing scientific methods to reduce the process times in the industries (Gupta et al., 2014, Taylor, 2004, Lopetegui et al., 2014). According to Hardin (1947), reducing labor costs and job costs is the ultimate goal in work simplification. Fedrick Taylor's work simplification methods allow for enhancing the results of work by increasing the efficiency of human labor, resulting in a significant increase in the worker's wage-earning capacity and an even greater decrease in the labor cost of the product (Thompson, 2003).

The principles of scientific management put forwarded by Fedrick Taylor have led to work simplification by building close co-operation between the management and the employees, and incorporating the concept: "Division of Labor" into the work process (Gupta et al., 2014). The main principles of scientific management extracted by Taylor (2004) are as follows.

- I. Developing a scientific method when designing a job i.e., by studying how it is currently done (simply by a TMS) and analyzing the data to approach the best possible way to fulfill the task/tasks.
- II. Taylor demonstrated the importance of matching the tasks to the employee. It is necessary to understand the strengths, weaknesses of the workers and to provide necessary training to help them improve their performance. Further, newly developed scientific methods of job design should not only be presented to an employee but should also be fully explained by the management.
- III. Introducing the piecework wage system to create a pricing system that enhanced the most efficient method in producing the product. Piecework wage system links the number of products produced in an hour (or a day) to higher wage rates if the worker exceeded a certain threshold. He also assumed that if employees understood the reasons for the change and demonstrated a desire for higher incomes for themselves, they would show little resistance to changes in methods.
- IV. Taylor believed that if the management and workers were truly dependent on one another, cooperation would naturally follow as explained in the concept of "Division of Labor". "Division of labor" is organizing the management system such that all work is distributed evenly among all workers within the company (Janoski and Lepadatu, 2014).

The theory of scientific management finally has resulted in the individualization of work (also called "functional foremanship") where each worker builds up a strong intention to produce more products or services so that they could earn higher wages (Janoski and Lepadatu, 2014). However, the main objective should

be to reduce the time, energy, or cost even in minor amounts to achieve significant results within an organization (Hodges, 1949).

### *3.1.1.2 Work simplification in the mushroom industry and introduction to the tilting shelf system*

The cost of production in the mushroom industry is steadily increasing every year (Van Dieten and Van Dijk, 2021, Wolf, 1977, Schiau, 2013) with labor for the harvesting process accounting for around 36 % of total production costs (Van Dieten, 2021a, Deckers, 2021). Hodges (1949) states that work that consists of repetitive action or that requires a lot of hand labor is highly valued, and well-designed, simple equipment is frequently the key to improvement. These findings highlight that technological advancements in mushroom farming is necessary even though it is more challenging than other agricultural fields due to the lack of prior knowledge in breeding and genetic systems, which could lead to new cultivation techniques that affect production yields and quality. (Chakravarty, 2011). Fortunately, GTL- Europe has taken the challenge of implementing a tilting shelf system with conveyor belts, and Rheinische Pilz Zentrale in Geldern has been the first farm to implement it approximately two years ago (site C) (Van Dieten, 2021b). GTL– Europe is currently working on this new system to reduce human labor through the use of scanning devices and robotic technology (Van Dieten, 2021d, GTL, 2021b). Changes in physical work, equipment, layout, production process and practices are important facts to consider when designing new equipment for work simplification (Davis, 1953).

Mushroom picking is the result of three main motions; twisting, bending, and lifting (Huang et al., 2020, Huang et al., 2021). The traditional method of mushroom

farming which was observed at farm's sites A/B has fixed shelves and automatically movable "lorries" where the picker could sit, pick mushrooms, cut the stems with a knife, sort champignons in the punnets and measure them using a 4-digit scale (Figure 1 and Figure 2). The lorries which work using a hydraulic system are controlled by the picker, and they can move horizontally and vertically along the shelves. In this system, only one hand is used to pick mushrooms as the picker is positioned at 90° to the shelf, and an experienced person can usually handle four to five mushrooms at once in one hand.



*Figure 1. A picker arranging champignons in the crate*



*Figure 2. A picker on the lorry picking champignons*

This study included a thorough examination of the newly introduced tilting shelf system by GTL- Europe, with conveyor belts at site C. The lorries automatically move horizontally and vertically along the shelves as in the traditional system. In comparison to the traditional system, the lorries here function according to the recipe settings that have been put in the main controlling system. The recipe settings could be prepared so that it suits each day of the flush, and the beds that needs to be picked can be tilted. The pickers who drive on these lorries pick the mushrooms using both hands and place them in the holes of the conveyor belt (also called the “pick belt”) that runs across the growing beds, towards the automatic cutting station outside the growing hall, and then to the packing station (Figure 3, Figure 4 and Figure 5).



*Figure 3. Tilted beds (beds 2 and 4) (left) and a picker harvesting champignons by both hands (right)*



*Figure 4. A conveyor belt with champignons moving towards the pack station*



*Figure 5. The packing station*

The packer takes the mushrooms from the belt, sorts them into punnets, and weighs them. Therefore, for one side of a growing bed, a picker will be inside the growing hall and a packer outside the growing hall. The picker and the packer work together as a team.

The recipe settings introduced by GTL-Europe (GTL, 2021a) and the farm manager at RPZ (Van Dieten, 2021d) includes if the picker is able to terminate the lorry as the controller wants during picking. It also allows to set up a maximum and a minimum lorry speed, a pick belt speed, and a foot knife speed (the speed of the knife which cut the stems). The speed of the lorry could be changed from 0 m/min to 6 m/min, while the pick belt speed can be changed between 50 picks/min and 120 picks/min. As there is an influence on the speed of the pick belt when the lorry and the pick belt are moving together, a pick belt speed compensation value is included. It aids in balancing the number of picks between the picker and the packer and allows the whole process to be functioning



smoothly without any interruptions. The pick belt speed compensation can be varied between 0 % to 100 % when the lorry is moving towards the pack station, and between -100% to 100% when the lorry is moving away from the pack station. The foot knife speed is determined upon the quality of the cut of the stems.

### 3.1.2 Time – motion studies

Time-motion studies are a quantitative data collection method where an external observer gathers precise data on the total time and motions required to complete a certain task, followed by an analysis aimed at increasing the efficiency of that task (Lopetegui et al., 2014, Johnston, 1956). Initially, this type of research has been used in the field of industrial engineering (Davis, 1953), and later the health care industry has adopted it for their studies (Finkler et al., 1993, Abbey et al., 2012). “Time” studies are extensive observations of workers, that uses a stopwatch to measure the time required to complete isolated events at a basic level (Taylor, 2004, Zheng et al., 2011, Russell and Taylor, 2006, Adam, 1992). While Zheng et al. (2011) explains the ‘motion’ study approach to make it more efficient. TMS is an integration of ‘time’ studies and ‘motion’ studies, that have been widely accepted in the field of scientific management (Lopetegui et al., 2014). Despite the fact that time studies and work measurements are useful instruments for improving work efficiency, they are not commonly used in agricultural research (Zain and Rajamony, 2014).

Work sampling and continuous observation are the two main techniques widely used in TMS and for both of these techniques data are gathered by an external observer (Finkler et al., 1993, Wirth et al., 1977, Pizziferri et al., 2005). Lopetegui

et al. (2014) has shown more methods in conducting TMS which are applicable such as self-reporting and using automatic time stamps (Figure 6). But in this study, the focus will only be on the two main methods mentioned. According to Lowery et al. (1940) and Lopetegui et al. (2014), in the continuous sampling method, the stopwatch runs continuously during the duration of observation and the time taken for each task is being recorded, such that the action of recording is triggered as a result of the subject's action. This system is effective for gathering data for non-centralized jobs, short tasks, and field data that is comprehensive (Lopetegui et al., 2014). In work sampling, data are collected at certain time intervals and these time intervals could be fixed or chosen at random (Finkler et al., 1993). This method is strongly applicable for studies with less frequent tasks (Barnett, 2008, Auernhammer, 1979).

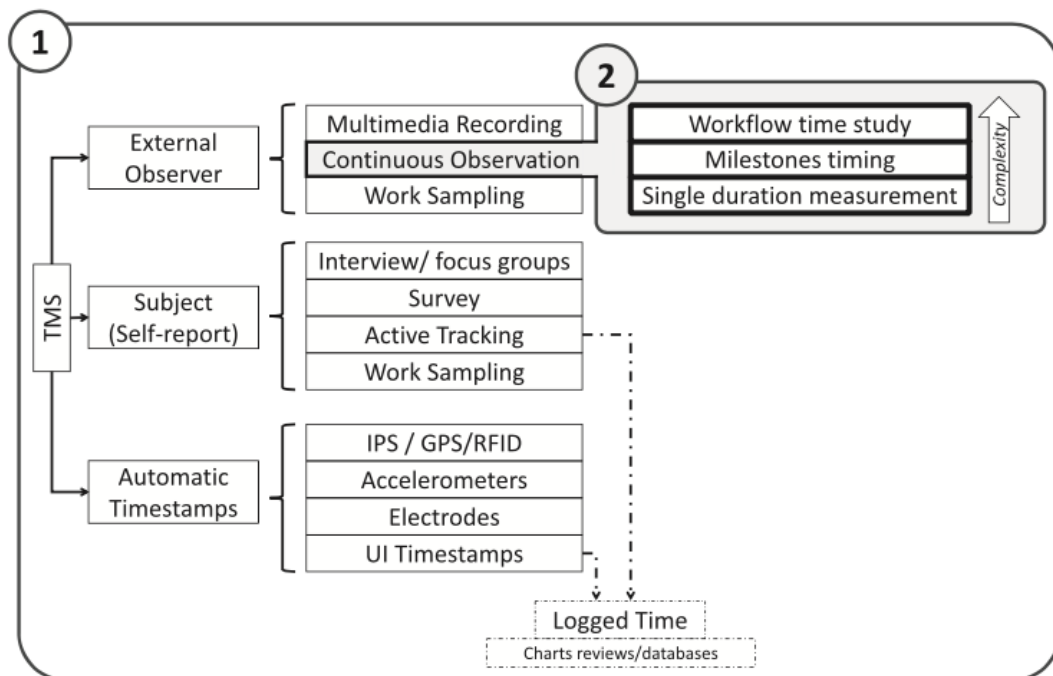
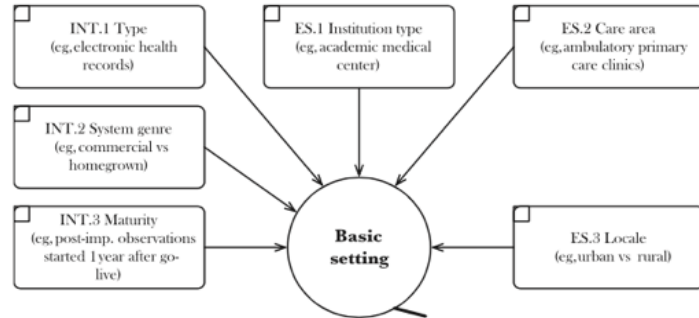


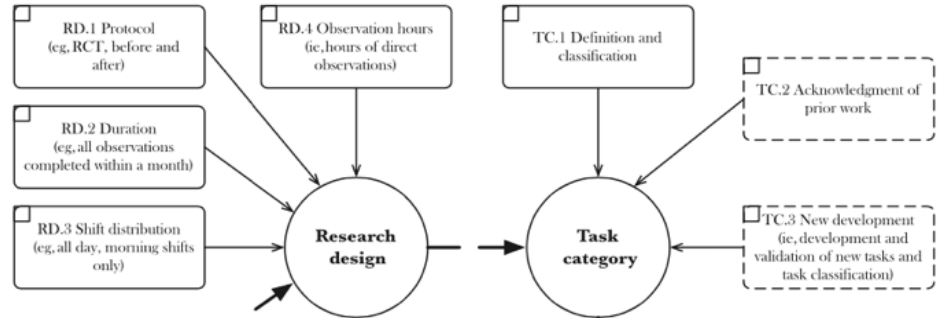
Figure 6. Methods of time-motion studies (Lopetegui et al., 2014)

Due to multiple inconsistencies occurring in TMS, Zheng et al. (2011) have made efforts to standardize the research methodologies in these investigations and it is referred to as STAMP. STAMP shows a certain criterion that the researchers could follow when they are planning their research. The criteria include eight main areas and they are, intervention (INT), empirical setting (ES), research design (RD), task category (TC), observer (OBS), subject (SUB), data recording (DR), and data analysis (DA) (Zheng et al., 2011). The flow chart (Figure 7) explains the whole process in summary and how to plan a TMS from the basic setting till the study execution.

### 1. Basic setting



### 2. Research design and planning



### 3. Study execution

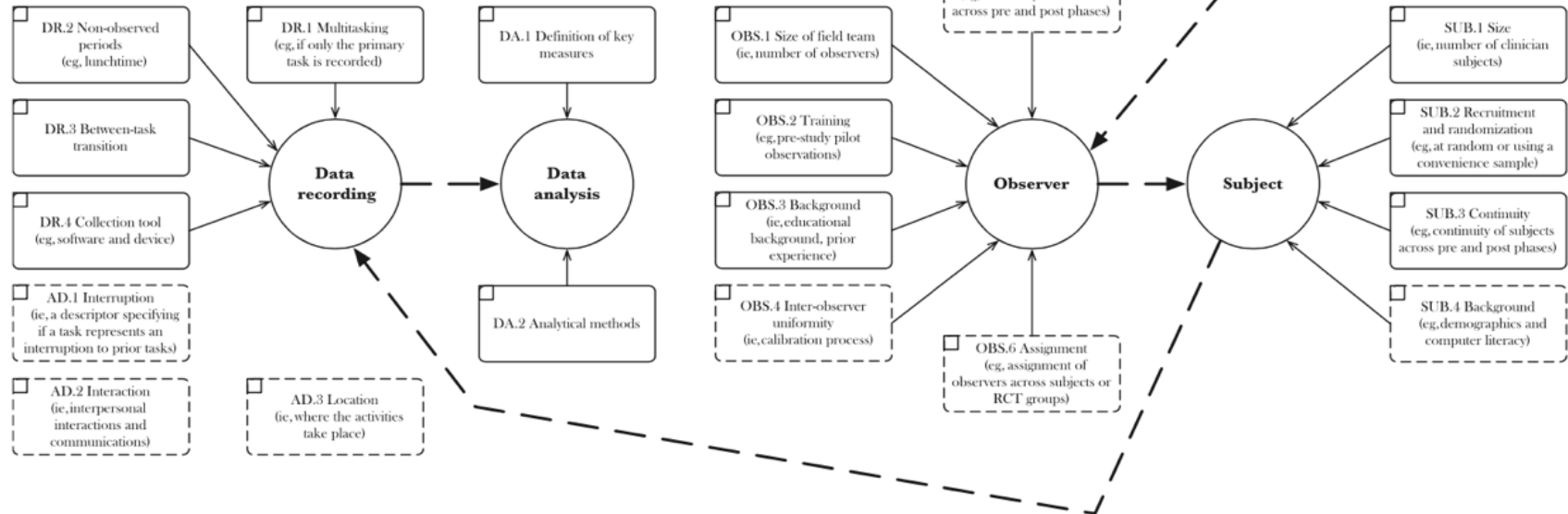


Figure 7. STAMP shown in a flow chart (dashed boxes may not be related to all studies) (Zheng et al., 2011)

### 3.1.3 IFEM, EFEM, SWOT and QSPM in strategic management

Strategic management is a series of decisions and actions performed by the management in partnership with all levels of the organization to determine its long-term performances (Yüksel and Dagdeviren, 2007). Abdolshah et al. (2018) introduces IFEM, EFEM, SWOT matrix and QSPM as few tools used in strategic management. The ultimate goal of the strategic planning process is the formulation and adoption of a strategy that creates a good relationship between the internal and external factors of a business (Oreski, 2012).

As the initial step for this, the key strategic factors are identified using the IEFM and EFEM (Feili et al., 2018). IFEM is used for analyzing internal strengths and weaknesses within a business, while EFEM is used to analyze the external opportunities and threats in the business (Putri and Riyanto, 2020, Leliga et al., 2019). Internal strengths and external opportunities aids in reaching the goals of the company, internal weaknesses impede the success of the company, and the external threats are obstacles or the potential obstacles to reach company's goals (Aldehayyat and Anchor, 2008, Fleisher and Bensoussan, 2003, Lee and Lin, 2008, Shrestha et al., 2004). Each factor of the IFEM and EFEM are rated between 1 and 4 and they are weighted (Ommani, 2011). According to Ommani (2011), all internal and external factors are assigned a total weight of 1.00 (100 %). Finally, a weighted score is calculated for each factor by multiplying the given rating by its weight.

SWOT stands for strengths, weaknesses, opportunities and threats, where strengths and weaknesses are internal factors of the business, weaknesses and opportunities are external factors of the business (Oreski, 2012). The goal of a

SWOT analysis is to identify and pick the most important issues and barriers by the external environment in which the organization operates, as well as the factors related to the company's internal development (Mandrazhi, 2021). The SWOT analysis according to Rangkuti (2006), is the methodical evaluation of numerous perspectives of the company to build a good strategy. The strategic elements are identified and analyzed by the managers to either support or hinder the organization's ability to reach its full potential (Houben et al., 1999, Namugenyi et al., 2019, Putri and Riyanto, 2020). The SWOT can be presented in a matrix format, and different combinations of the matrix's four components can aid in determining a plan that will result in long-term growth (Oreski, 2012). It is important to know that SWOT should not be viewed as a one-dimensional analytical tool focused only on the results, but rather as a dynamic component of the management and company's growth process (Pickton and Wright, 1998).

QSPM is a literature-based analytic tool to determine the relative attractiveness of alternative solutions/ suggested strategies (brought up by the SWOT analysis) (Putri and Riyanto, 2020). QSPM is primarily used to facilitate decision-making and problem-solving procedures (Feili et al., 2018). This matrix uses information from IFEM, EFEM, SWOT analysis and the suggested strategies formulated are objectively evaluated (Abdolshah et al., 2018). An attractiveness score (AS) shows how relevant or attractive it is to the suggested strategies (Ommani, 2011). The attractiveness score lies between 1 and 4; 1 indicates not attractive and 4 indicates highly attractive (Ommani, 2011). The total attractiveness score (TAS) is calculated by multiplying each factor's weight by its AS. The sum of the TAS for each alternative strategy provides a ranking, making it easier to decide which strategy is the most significant (Ommani, 2011).

## 3.2 Traditional champignon farm (Sites A/B)

### 3.2.1 Time – motion studies for activities other than picking

Crate changes while picking consumed 25% of non-picking time and is the most time-consuming non-picking activity identified (Table 1). Unloading the filled crates and entering the data into the system which accounts for 20% of the total time taken for non-picking activities was the second highest time-consuming activity (Table 1). The third highest time-consuming activities were bringing and loading crates and information exchange and walking (Table 1). The lowest time-consuming activity was identified as preparing the workspace which is 3 % of the non-picking time (Table 1).

*Table 1. Average time  $\pm$  SE taken for activities before changes*

Activity	No. of replicates	Average time $\pm$ SE (mins hr <sup>-1</sup> )	As a % of total time taken for non-picking activities
Throwing away stems	26	1.60 $\pm$ 0.23	5 %
Unloading filled crates and entering data to the system	26	5.77 $\pm$ 0.62	20 %
Bringing and loading new crates	26	5.12 $\pm$ 0.56	17.5 %
Preparing the work space	26	0.76 $\pm$ 0.16	3 %
Exchange information and walking	26	5.12 $\pm$ 0.94	17.5 %
Lorry movements and adjustments	26	3.56 $\pm$ 0.59	12 %
Crate change	26	7.30 $\pm$ 0.33	25 %

Table 2. Average time  $\pm$  SE taken for activities after changes

Activity	No. of replicates	Average time $\pm$ SE (mins hr <sup>-1</sup> )	As a % of total time taken for non-picking activities
Throwing away stems	26	1.77 $\pm$ 0.28	6 %
Unloading filled crates and entering data to the system	26	4.41 $\pm$ 0.59	16 %
Bringing and loading new crates	26	2.94 $\pm$ 0.32	11 %
Preparing the work space	26	1.31 $\pm$ 0.31	5 %
Exchange information and walking	26	4.18 $\pm$ 0.75	15 %
Lorry movements and adjustments	26	4.82 $\pm$ 0.80	17 %
Crate change	26	8.39 $\pm$ 0.77	30 %

After making improvements in the management, a further increase in the average time taken for crate changes was resulted, and it is again the highest time-consuming activity (30 %) (Table 2). The areas where the changes i.e., in shortening the walking distance to the crates and giving clear instructions were made, showed a reduction between 2.5 % and 6.5 % of the time taken before making changes (by comparing Table 1 and Table 2 ). Further, an increase in the time taken for lorry movements and adjustments after changes was notable and it was the second highest time-consuming activity identified (Table 2).

Table 3. Statistical results of average times before and after changes

Activity	P value	T value	Degrees of freedom
Throwing away stems	0.72	NA	NA
Unloading filled crates and entering data to the system	0.09	NA	NA
Bringing and loading new crates	4.35 $\times$ 10 <sup>-3*</sup>	3.13	25
Preparing the work space	0.43	NA	NA
Exchange information and walking	0.79	NA	NA
Lorry movements and adjustments	0.22	NA	NA
Crate change	0.21	1.27	25

p < 0.05 considered as significant, shown by \*, if p > 0.05, considered as not significant. NA: Not applicable



A significant p value was obtained only for the difference in the average time taken to bring and load new crates (Table 3). It should be noted that even though a statistically significant p value was not obtained in the results of exchanging information and walking (Table 3), still there is a reduction in the average time taken after changes were made (compare Table 1 and Table 2). The T values obtained were not close to 0, meaning the average time before and after were not similar (or almost similar) (Table 3). The degrees of freedom obtained for crate changes and bringing and loading new crates were high (25) (compared to the sample size = 26) showing that there is more power to reject the null hypothesis ( $H_0$  = average is equal to zero) and to accept the alternative hypothesis ( $H_{alt}$  = average is not equal to zero) (Table 3).

### 3.2.2 Average weights of white champignons (strain 737)

Average weight of a champignon belonging to 30 mm size class weighed  $10.45 \pm 1.71$  g in the first flush and  $8.41 \pm 1.52$  g in the second flush ( Figure 8). Average weight of a champignon which belongs to 40 mm weighed  $20.83 \pm 1.13$  g in the first flush and  $18.58 \pm 0.68$  g in the second flush ( Figure 8). A 60 mm champignon weighed  $53.99 \pm 3.35$  g in the first flush and  $50.22 \pm 1.51$  in the second flush and a 60 + mm champignon weighed  $71.81 \pm 3.90$  g in the first flush and  $67.97 \pm 6.56$  g in the second flush ( Figure 8). Finally, a canning champignon weighed  $47.52 \pm 3.60$  g in average in the first flush and  $45.37 \pm 9.19$  g in the second flush ( Figure 8).

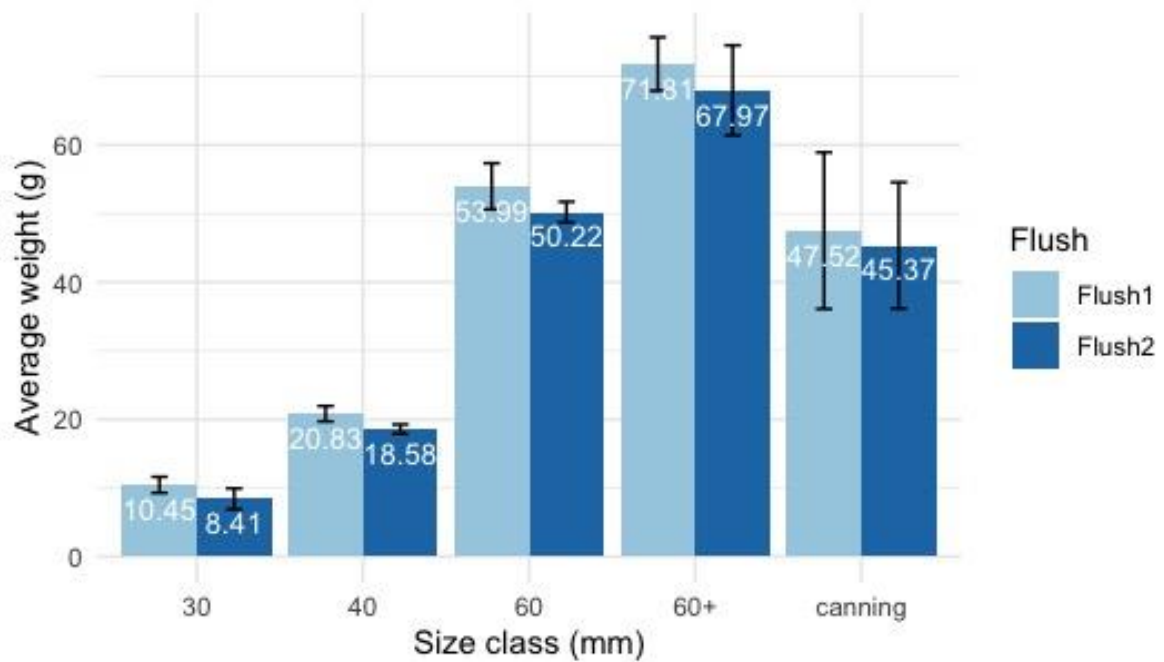


Figure 8. Comparison of average weights  $\pm$ SD (g) of white champignons per size class in 1<sup>st</sup> and 2<sup>nd</sup> flush.

The distribution of weights and the error bars of canning and 60 + mm champignons were quite large when compared to the other size classes (Figure 9). Several outliers were also identified in the boxplots of the 30 mm champignons (in both flushes) and the canning champignons (in flush 1) (Figure 9). The boxplots of size classes 30 mm and 40 mm champignons were very condensed, and it was difficult to interpret if the distribution of the data were normally distributed, positively skewed or negatively skewed (Figure 9).

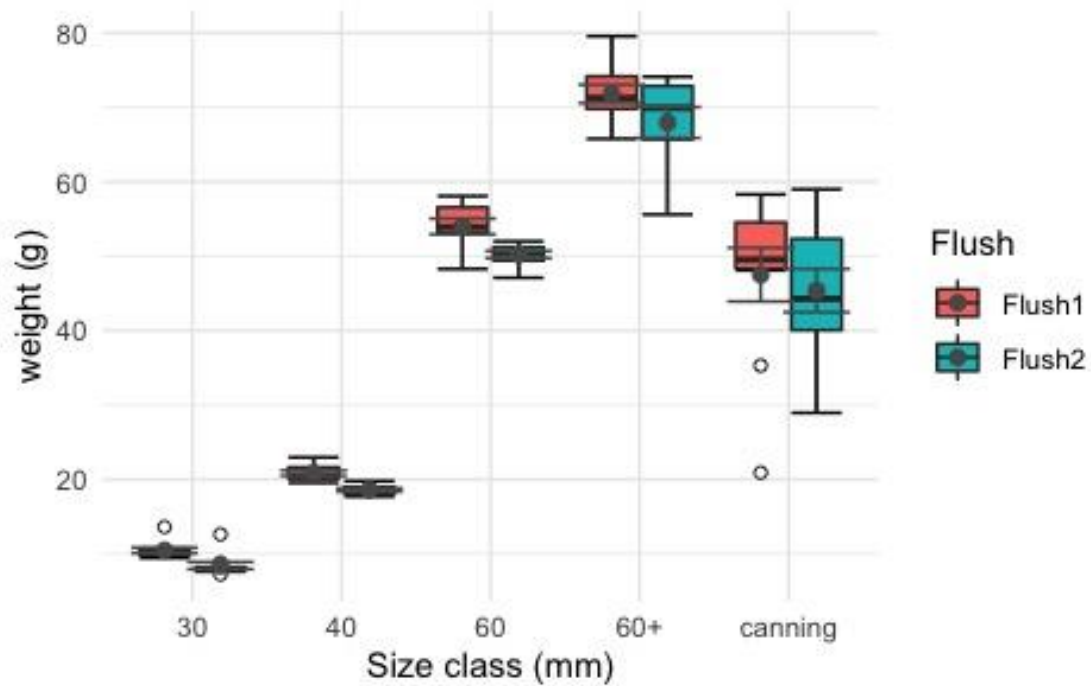


Figure 9. Representation of distribution of weights (g) of white champignons per size class with error bars. Black dots represent the average weights. Black circles represent outliers.

The average weight of a flush 1 white champignon regardless of size class was found out to be 50.42 g with a standard error of 1.40 and a flush 2 champignon was 40.16 g with a standard error of 1.39 (APPENDIX C). In the calculations to find the pick rates by the database (Table 6 and Table 7), they were considered as 50 g and 40 g in the 1<sup>st</sup> and 2<sup>nd</sup> flush respectively. A higher average median value (50.88 g) was obtained in the 1<sup>st</sup> flush than in the second flush (39.52 g) (Figure 10). Several outliers were observed in the average weights of flush 1 champignons (Figure 10). Flush 1 and 2 showed nearly a normal distribution, but it is slightly positively skewed (Figure 10).

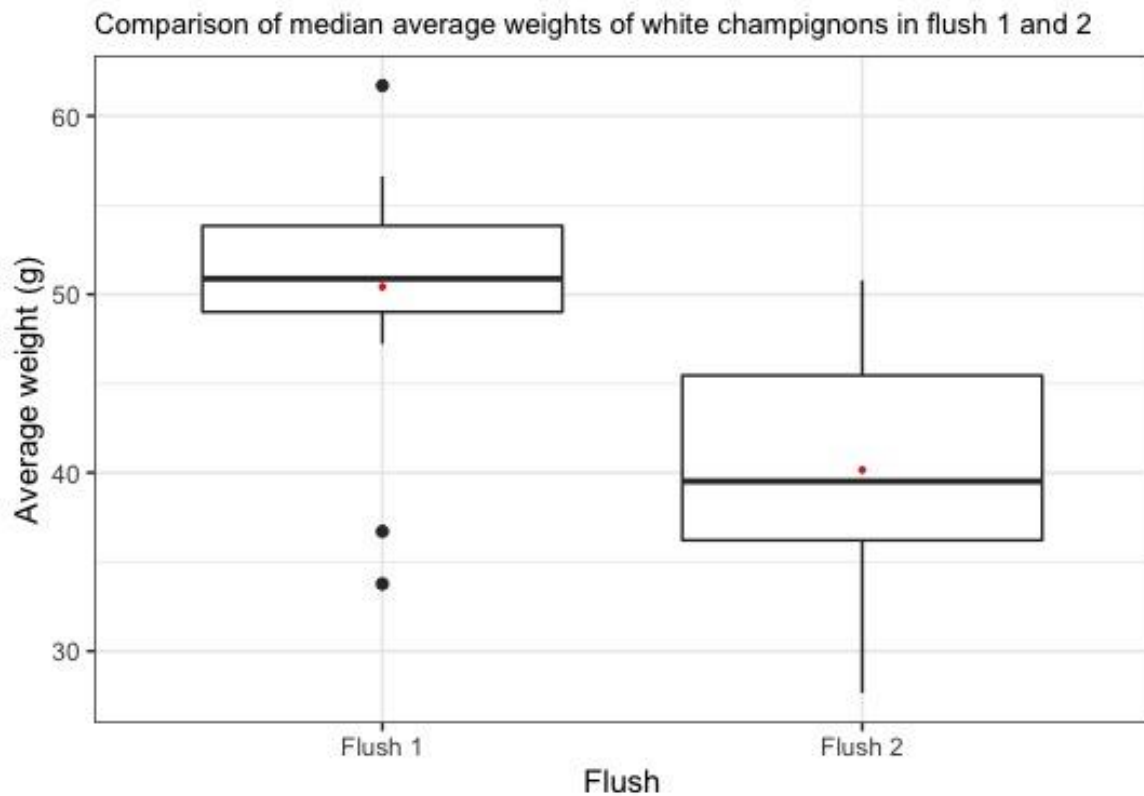


Figure 10. Comparison of median average weights (Regardless of size class) in 1st and 2nd flush. Red dots represent the average weights (Regardless of size class). Black dots represent outliers, Box = 25<sup>th</sup> and 75<sup>th</sup> percentiles; bars = min and max values.

### 3.2.3 Finding pick rates by observation

The average pick rate by observation during the first flush was 28 picks per minute (Table 4).

Table 4. Pick rates by observation during the first flush.

Picker	Flush	Picks/5min	Picks/min
1	1	162	32.4
2	1	82	16.4
3	1	125	25
4	1	164	32.8
5	1	123	24.6
6	1	150	30
7	1	152	30.4
8	1	155	31
9	1	174	34.8
10	1	164	32.8
11	1	115	23
12	1	151	30.2
13	1	138	27.6
14	1	162	32.4
15	1	130	26
16	1	143	28.6
17	1	160	32
18	1	155	31
19	1	123	24.6
20	1	167	33.4
21	1	159	31.8
22	1	145	29
23	1	156	31.2
24	1	90	18
25	1	134	26.8
26	1	115	23
Average picks/min			28

The pick rate during the second flush was concluded as 19 picks per minute (Table 5).

Table 5. Pick rates by observation during the second flush.

Picker	Flush	Picks/5min	Picks/min
1	2	118	23.6
2	2	105	21
3	2	110	22
4	2	111	22.2
5	2	69	13.8
6	2	67	13.4
7	2	35	7
8	2	57	11.4
9	2	130	26
10	2	123	24.6
11	2	122	24.4
12	2	125	25
13	2	102	20.4
14	2	141	28.2
15	2	150	30
16	2	131	26.2
17	2	136	27.2
18	2	84	16.8
19	2	79	15.8
20	2	61	12.2
21	2	56	11.2
22	2	185	37
23	2	75	15
24	2	65	13
25	2	57	11.4
26	2	37	7.4
Average picks/min			19

### 3.2.4 Finding pick rates by the data base and the picking efficiencies

#### 3.2.4.1 Before changes in the management.

The picking efficiency was 39 % in average from both the flushes before making changes in the management (Table 6).

Table 6. Picking efficiency (%) before changes in the management.

Flush	Total kg harvested	Total working hours	Avg. weight of a champignon (g)	No of champignons	champignons/hr	champignons /min (by database)	champignons/min (by observation)	Picking efficiency %
1	19325.9	670.12	50	386518	577	10	28	34%
1	19696.7	641.88	50	393934	614	10	28	37%
1	18367.6	622.61	50	367352	590	10	28	35%
1	25212.1	831.53	50	504242	606	10	28	36%
1	42199.4	1447.14	50	843988	583	10	28	35%
1	15272.3	459.39	50	305446	665	11	28	40%
1	20767.4	743.81	50	415348	558	9	28	33%
1	18367.6	622.61	50	367352	590	10	28	35%
1	20480.6	726.6	50	409612	564	9	28	34%
1	16517.3	513.72	50	330346	643	11	28	38%
1	20905.1	670.68	50	418102	623	10	28	37%
1	21245.7	902.23	50	424914	471	8	28	28%
1	21827.2	679.15	50	436544	643	11	28	38%
1	20565.9	694.7	50	411318	592	10	28	35%
1	20617.6	611.26	50	412352	675	11	28	40%
2	12258.9	599.99	40	306472.5	511	9	19	45%
2	14061.1	637.06	40	351527.5	552	9	19	48%
2	10404.3	523.05	40	260107.5	497	8	19	44%
2	8759.7	381.72	40	218992.5	574	10	19	50%
2	13065.7	772.38	40	326642.5	423	7	19	37%
2	14079.7	799.17	40	351992.5	440	7	19	39%
2	14389.5	705.57	40	359737.5	510	8	19	45%
2	15438.4	794.75	40	385960	486	8	19	43%
2	12089.9	690.58	40	302247.5	438	7	19	38%
2	12549.5	705.67	40	313737.5	445	7	19	39%
2	8247.8	518.43	40	206195	398	7	19	35%
2	11088.7	511.63	40	277217.5	542	9	19	48%
2	11153	633.61	40	278825	440	7	19	39%
2	11073.5	541.09	40	276837.5	512	9	19	45%
2	12146.1	653.61	40	303652.5	465	8	19	41%
Average picking efficiency of the farm								39%

This shows the actual picking time at sites A/B for one hour is around 23.4 minutes. The rest of the time is taken for the activities other than picking.

#### *3.2.4.2 After changes in the management*

The picking efficiency was increased to 43 % in average from both flushes after making changes in the management (Table 7) meaning, the actual picking time was increased by 2.4 minutes.



Table 7. Picking efficiency (%) after changes in the management.

Flush	Total kg harvested	Total working hours	Avg. weight of a mushroom (g)	No of mushrooms	mushrooms/hr	mushrooms /min (by database)	mushrooms/min (by observation)	Picking efficiency %
1	20845	629.7	50	416900.0	662	11	28	39%
1	21680.9	848.28	50	542022.5	639	11	28	38%
1	20436.7	711.1	50	408734.0	575	10	28	34%
1	16653.2	570.61	50	416330	730	12	28	43%
1	19271.1	571.0	50	385422.0	675	11	28	40%
1	19214.1	728.05	50	480352.5	660	11	28	39%
1	19624.1	667.7	50	392482.0	588	10	28	35%
1	17932.4	626.74	50	448310	715	12	28	43%
1	19650	698.09	50	393000	563	9	28	34%
1	19221.5	763.16	50	480537.5	630	10	28	37%
1	17747.2	339.65	50	354944	1045	17	28	62%
1	21566.7	739.35	50	539167.5	729	12	28	43%
1	20048.4	487.5	50	400968	822	14	28	49%
1	17352.5	612.32	50	433812.5	708	12	28	42%
1	20236.1	675.44	50	404722	599	10	28	36%
2	12339.2	545.13	40	246784	453	8	19	40%
2	10839.7	625.39	40	216794	347	6	19	30%
2	10788.5	490.86	40	215770	440	7	19	39%
2	10211	516.1	40	204220	396	7	19	35%
2	11654.9	548.49	40	233098	425	7	19	37%
2	10699.8	473.99	40	213996	451	8	19	40%
2	15002	583.3	40	375050	643	11	19	56%
2	14673.1	612.02	40	366827.5	599	10	19	53%
2	10646.1	442.02	40	266152.5	602	10	19	53%
2	13377.5	729.94	40	334437.5	458	8	19	40%
2	14340.7	688.6	40	358517.5	521	9	19	46%
2	12504.6	577.72	40	312615	541	9	19	47%
2	11527.4	478.04	40	288185	603	10	19	53%
2	15108	747.3	40	377700	505	8	19	44%
2	11743.3	534.25	40	293582.5	550	9	19	48%
Average picking efficiency of the farm								43%

### 3.3 Technically advanced champignon farm (Site C)

#### 3.3.1 Time – motion studies for activities other than picking

The packers were the ones who were engaged in most of the other activities compared with the pickers, therefore the packers were considered in this study. The highest time-consuming activity among the non-picking activities was the waiting time, which accounted 44.45 % of total time taken for non-picking activities (Table 8). Apart from that, technical problems accounted for 17.14 % of the total non-picking time, for cleaning: 12.95 % and crate changes: 25.46 % of total non-picking time (Table 8). The total time in average spent for non-picking activities was 28.12 minutes per hour (obtained by adding all the average times for the activities)

*Table 8. Average time  $\pm$  SE taken for activities before changes*

Activity	No. of replicates	Average time $\pm$ SE (mins hr <sup>-1</sup> )	As a % of total time taken for non-picking activities
Crate change	20	7.16 $\pm$ 0.64	25.46 %
Waiting time	20	12.50 $\pm$ 0.90	44.45 %
Technical problems	20	4.82 $\pm$ 0.50	17.14 %
Cleaning	20	3.64 $\pm$ 0.85	12.94 %

A reduction in the average waiting time consumed for technical problems was resulted after the changes were done, while the average time taken for crate changes increased (Table 9). But still percentage wise, the highest time consumed activity was the waiting time (Table 9). Average time accounted for cleaning was the lowest after changes as well (Table 9). The total time in average

spent for non-picking activities was 26.24 minutes per hour after the improvements (found out by adding the average times per activity) (Table 9).

*Table 9. Average time  $\pm$  SE taken for activities after changes*

Activity	No. of replicates	Average time $\pm$ SE (mins hr <sup>-1</sup> )	As a % of total time taken for non-picking activities
Crate change	20	7.99 $\pm$ 0.70	30.44 %
Waiting time	20	12.47 $\pm$ 1.29	47.52 %
Technical problems	20	2.20 $\pm$ 0.48	8.38 %
Cleaning	20	3.58 $\pm$ 0.43	13.64 %

A significant p value was obtained for results of technical problems of the farm (Table 10). T value of waiting time (0.02) is very small interpreting that the difference between the two average values (before and after) were very small (Table 10). The degrees of freedom obtained for the waiting time was high (compared to the sample size = 20) showing that there is more power to reject a false null hypothesis ( $H_0$  = average is equal to zero) and to accept the alternative hypothesis ( $H_{alt}$  = average is not equal to zero) (Table 10).

*Table 10. Statistical results of average times before and after changes*

Activity	P value	T value	Degrees of freedom (df)
Crate change	0.38	NA	NA
Waiting time	0.98	0.02	19
Technical problems	3.56 $\times$ 10 <sup>-3</sup> *	NA	NA
Cleaning	0.67	NA	NA

p < 0.05 considered as significant, shown by \*, if p > 0.05, considered as not significant. NA: Not applicable

### 3.3.2 Average weights of brown champignons (strain Heirloom)

Average weight of a champignon belonging to 30 mm size class weighed  $10.93 \pm 0.98$  g in the first flush and  $8.16 \pm 0.47$  g in the second flush ( Figure 11). Average weight of a champignon which belongs to 40 mm weighed  $18.35 \pm 2.60$  g in the first flush and  $16.21 \pm 1.20$  g in the second flush ( Figure 11). A 60 mm champignon weighed  $51.17 \pm 3.08$  g in the first flush and  $43.48 \pm 8.90$  g in the second flush ( Figure 11). A 60 + mm champignon weighed  $77.25 \pm 6.61$  g in the first and  $55.38 \pm 10.79$  g in the second flush ( Figure 11). Finally, a canning champignon weighed  $42.64 \pm 10.93$  g in average in the first flush and  $39.33 \pm 12.46$  g in the second flush ( Figure 11).

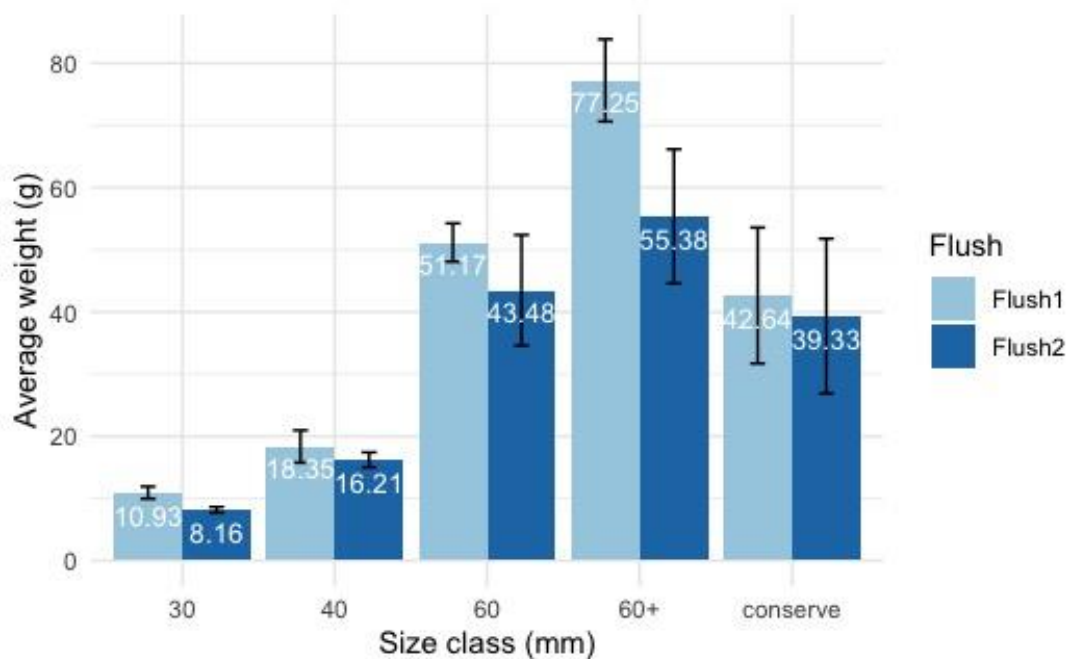


Figure 11. Comparison of average weights  $\pm$ SD (g) of brown champignons in 1st and 2<sup>nd</sup> flush.

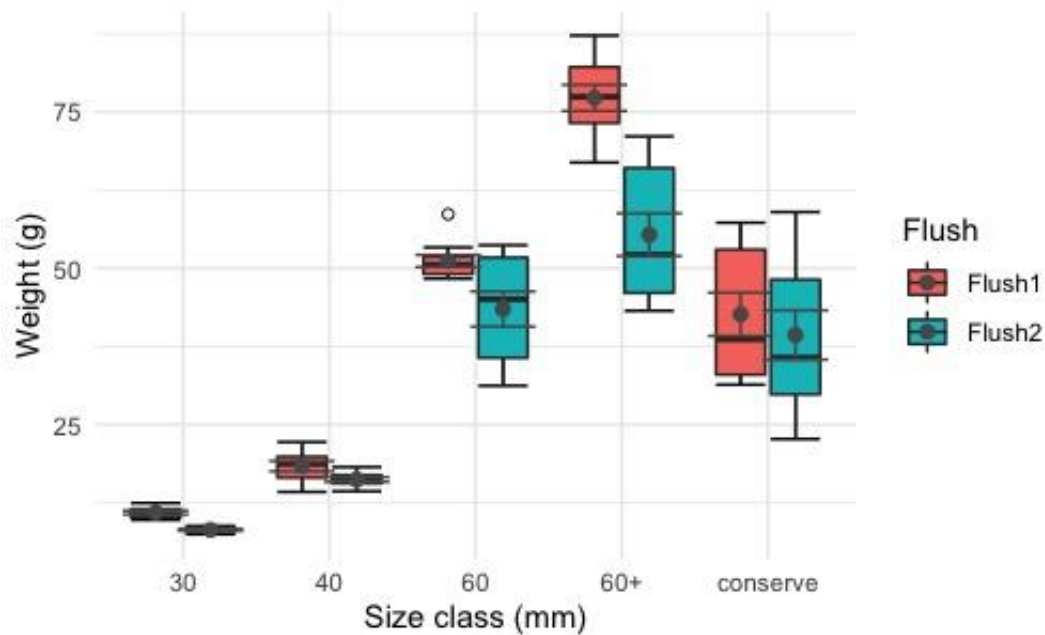


Figure 12. Representation of distribution of weights of brown champignons per size class with error bars. Black dots represent the average weights. Black circles represent outliers.

The distribution of weights in classes 60 mm (in the second flush), 60 + mm and canning were quite large compared to the 40 mm and 30 mm champignons (Figure 12). The weight distribution of the 30 mm and 40 mm champignons and their error bars were very narrow compared to the other classes (Figure 12). One outlier was identified in the boxplot of the 60 mm, flush one champignons (Figure 12).

The average weight  $\pm$  SE of a flush 1 brown champignon regardless of size class was found out to be  $44.14 \pm 0.69$  g and a flush 2 champignon was  $37.25 \pm 1.07$  g regardless of size class (Figure 13) (APPENDIX D). In the calculations to find picking efficiency (Table 13 and Table 14), they were considered as 44 g and 37 g respectively.

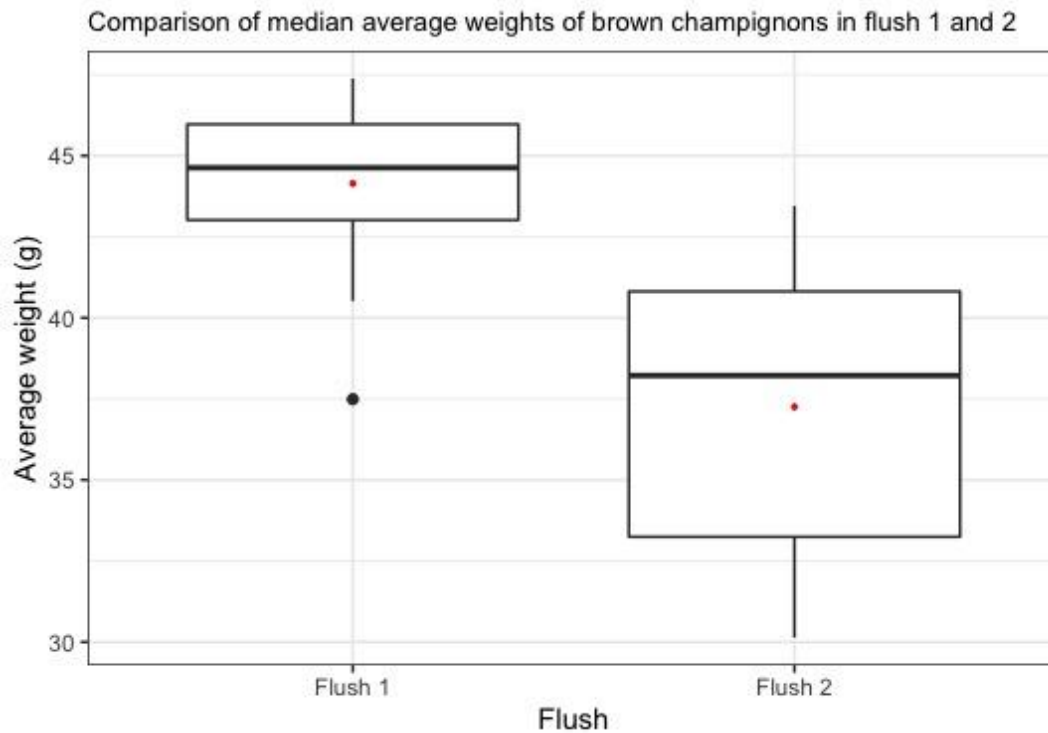


Figure 13. Comparison of median average weights (Regardless of size class) in 1st and 2nd flush. Red dots represent the average weights (Regardless of size class). Black dots represent outliers. Box = 25th and 75th percentiles; bars = min and max values.

A higher median value (44.63 g) was identified in the 1<sup>st</sup> flush than in the second flush (38.22 g) (Figure 13). Both boxplots show a negative skewness, and one outlier was identified from the data of the first flush (Figure 13).

### 3.3.3 Finding pick rates by observation

Picks/ 5 minutes is the average pick rate from the team, and it was converted to picks/minute, and divided by two to find out the pick/min per team member (Table 11 and Table 12). The average pick rate was concluded as 24 picks per minute during the first flush (Table 11).

Table 11. Pick rates by observation of selected teams during first flush.

Team	Flush	Picks/5min	Picks/min (Picker and packer)	Picks/min (per person)
1	1	270	54	27
2	1	297	59.4	29.7
3	1	120	24	12
4	1	229	45.8	22.9
5	1	230	46	23
6	1	120	24	12
7	1	210	42	21
8	1	322	64.4	32.2
9	1	150	30	15
10	1	267	53.4	26.7
11	1	306	61.2	30.6
12	1	321	64.2	32.1
13	1	339	67.8	33.9
14	1	305	61	30.5
15	1	287	57.4	28.7
16	1	245	49	24.5
17	1	230	46	23
18	1	194	38.8	19.4
19	1	150	30	15
20	1	90	18	9
Average picks/min			47	24

The average pick rate during a second flush was concluded as 19 picks per minute (Table 12).

Table 12. Pick rates by observation of the teams during the second flush.

Team	Flush	Picks/5min	Picks/min (Picker and packer)	Picks/min (per person)
1	2	106	21.2	10.6
2	2	132	26.4	13.2
3	2	268	53.6	26.8
4	2	187	37.4	18.7
5	2	218	43.6	21.8
6	2	237	47.4	23.7
7	2	214	42.8	21.4
8	2	313	62.6	31.3
9	2	225	45	22.5
10	2	293	58.6	29.3
11	2	312	62.4	31.2
12	2	100	20	10
13	2	130	26	13
14	2	130	26	13
15	2	130	26	13
16	2	138	27.6	13.8
17	2	127	25.4	12.7
18	2	150	30	15
19	2	206	41.2	20.6
20	2	200	40	20
Average picks/min			38	19

### 3.3.4 Finding pick rates by the data base and the picking efficiencies

#### 3.3.4.1 Before making improvements

Average picking efficiency of the 1<sup>st</sup> and 2<sup>nd</sup> flush before making improvements was found out to be 49 % (Table 13). This shows that out of 60 minutes, the actual picking time was 29.4 minutes.



Table 13. Picking efficiency (%) before changes.

Flush	Total kg harvested	Total working hours	Avg. weight of a champignon (g)	No of champignon	champignons/hr	champignons /min	champignons/min (by observation)	Picking efficiency %
1	11561.3	383.78	44	262756.8	685	11	24	48%
1	11652.5	373.35	44	264829.5	709	12	24	49%
1	10628.2	447.92	44	241550.0	539	9	24	37%
1	10700.7	424.01	44	243197.7	574	10	24	40%
1	6250.1	276.98	44	142047.7	513	9	24	36%
1	9950.3	344.63	44	226143.2	656	11	24	46%
1	11540.3	361.03	44	262279.5	726	12	24	50%
1	9758.1	298.33	44	221775.0	743	12	24	52%
1	11362.8	357.9	44	258245.5	722	12	24	50%
1	11652.5	373.35	44	264829.5	709	12	24	49%
1	11561.3	383.78	44	262756.8	685	11	24	48%
1	10558.2	336.95	44	239959.1	712	12	24	49%
1	11583.3	379.48	44	263256.8	694	12	24	48%
1	10476	474.15	44	238090.9	502	8	24	35%
1	10411.4	397.37	44	236622.7	595	10	24	41%
2	10762.7	558.68	37	290883.8	521	9	19	46%
2	5463.4	327.09	37	147659.5	451	8	19	40%
2	5525.9	200.18	37	149348.6	746	12	19	65%
2	4408.6	265.66	37	119151.4	449	7	19	39%
2	4890.6	266.56	37	132178.4	496	8	19	43%
2	5578.3	264.47	37	150764.9	570	10	19	50%
2	5557.8	327.42	37	150210.8	459	8	19	40%
2	5872.1	287.26	37	158705.4	552	9	19	48%
2	7425.4	390.28	37	200686.5	514	9	19	45%
2	5593.9	200.18	37	151186.5	755	13	19	66%
2	4270	124.98	37	115405.4	923	15	19	81%
2	2727.2	102.46	37	73708.1	719	12	19	63%
2	6520.2	302.65	37	176221.6	582	10	19	51%
2	3243	134.17	37	87648.6	653	11	19	57%
2	6041.2	297.93	37	163275.7	548	9	19	48%
Average picking efficiency of the farm								49%

#### *3.3.4.2 After making improvements*

The picking efficiency was increased to 54 % in average from both the flushes after making improvements (Table 14). This indicates the overall picking time was increased by 3 minutes.

Table 14. Picking efficiency (%) after changes.

Flush	Total kg harvested	Total working hours	Avg. weight of a champignon (g)	No of champignons	champignons/hr	champignons /min	champignons/mi n (by observation)	Picking efficiency %
1	12531.1	350.95	44	284797.7	812	14	24	56%
1	6993.7	183.75	44	158947.7	865	14	24	60%
1	8600.3	272.67	44	195461.4	717	12	24	50%
1	11618	391.83	44	264045.5	674	11	24	47%
1	11559.5	349.17	44	262715.9	752	13	24	52%
1	11469.2	371.26	44	260663.6	702	12	24	49%
1	9604.8	332.74	44	218290.9	656	11	24	46%
1	10161	335.56	44	230931.8	688	11	24	48%
1	9700.4	272.52	44	220463.6	809	13	24	56%
1	9276.9	301.41	44	210838.6	700	12	24	49%
1	11978	293.28	44	272227.3	928	15	24	64%
1	11133.8	316.98	44	253040.9	798	13	24	55%
1	10829.9	374.03	44	246134.1	658	11	24	46%
1	11975.4	381.93	44	272168.2	713	12	24	49%
1	12850.9	297.87	44	292065.9	981	16	24	68%
2	4864.6	193.44	37	131475.7	680	11	19	60%
2	3722	128.97	37	100594.6	780	13	19	68%
2	5153.2	270.58	37	139275.7	515	9	19	45%
2	4171.6	179.87	37	112745.9	627	10	19	55%
2	6520.2	302.65	37	176221.6	582	10	19	51%
2	4594.7	218.98	37	124181.1	567	9	19	50%
2	3380.7	120.13	37	91370.3	761	13	19	67%
2	4845.5	261.93	37	130959.5	500	8	19	44%
2	6014.6	278.64	37	162556.8	583	10	19	51%
2	5761.7	227.45	37	155721.6	685	11	19	60%
2	4825.8	239.44	37	130427.0	545	9	19	48%
2	5551.8	291.49	37	150048.6	515	9	19	45%
2	6708.3	379.44	37	181305.4	478	8	19	42%
2	6768.5	261.01	37	182932.4	701	12	19	61%
2	5983.8	201.47	37	161724.3	803	13	19	70%
Average picking efficiency of the farm								54%

### 3.4 Internal and External Factors Evaluation Matrices

The internal factors and external factors considered were quantitatively analyzed by providing weights, ratings, and weighted scores (Table 15 and Table 16). Critical discussions were made during assigning the weights and ratings for each factor so that unbiased quantification can be done upon their experiences.

The weighing system of each factor was adapted by David et al. (2009a), Oreski (2012) and Ommani (2011). A weight was assigned between 0.00 and 1.00 for each factor. This weight shows the relative importance of each factor in the perspective of the farm manager and the growing manager. Zero means the factor is not so relevant while 1 means it's highly relevant. The total weight had to be 1.00 for all the internal factors (strengths and weaknesses) and 1.00 for all the external factors (opportunities and threats).

The rating system which was adapted by David et al. (2009a) and Ommani (2011) shows how well the company's existing plans respond to each factor. It represents if the internal factor is a major weakness (rating = 1), a minor weakness (rating = 2), a minor strength (rating = 3), or a major strength (rating = 4). If the external factor was a major threat, rating 1 was given, if it was a minor threat rating 2 was given, for a minor opportunity rating 3 was given and if it was a major opportunity rating 4 was given. Therefore, with this rating system, the weaknesses and threats were assigned rating 1 or 2, strengths and opportunities with rating 3 or 4. Finally, the weights were multiplied by the given rating to obtain the weighted score for each factor and by adding the weighted scores the total

weighted score for strengths, weaknesses, opportunities, and threats (Table 15 and Table 16) were individually found out.

*Table 15. Internal factors evaluation matrix*

	<b>Internal factor</b>	<b>Weight</b>	<b>Rating</b>	<b>Weighted score</b>
Strengths	Have introduced new technology within the farm (site C)	0.05	4	0.2
	Having growers with long-term experience	0.05	4	0.2
	Having a long-term and large customer base	0.10	4	0.4
	Receiving compost and substrate from reliable companies	0.10	4	0.4
	Having well experienced harvesting managers and supervisors to assist	0.10	4	0.4
	Possibility of having training programs for the pickers	0.05	4	0.2
	Possibility of investing in modern technology and maintaining the resources which are existing	0.05	4	0.2
	Total	0.5		2.0
Weaknesses	Mushroom growing requires natural raw material	0.14	1	0.14
	Having too many varieties to sort	0.05	1	0.05
	Constant change in pickers	0.20	1	0.20
	Technical problems with the new system and the lorries	0.03	2	0.06
	No constant, long-term analysis of the performance of the supervisors and their pickers	0.08	1	0.08
	Total	0.5		0.53
	Total weighted score	1.00		2.53

The most relevant strengths according to the weights given were having a long-term and large customer base, receiving compost and substrate from reliable companies, and having well experienced harvesting managers and supervisors (Table 15). The strengths received a total score of 2.0 (Table 15). Among the weaknesses, the requirement of natural raw material for mushroom growing was identified as a highly relevant weakness with a weight of 0.14 (Table 15). Most of the identified weaknesses were considered as major weaknesses within the farm. The total score of the weaknesses was 0.53 (Table 15). Based on these results the total weighted score for all the internal factors was 2.53 (Table 15).

The most important external factor which contributed to the success of the business was identified as “Development of information technology” with a weight of 0.20 (Table 16). The opportunities received a total score of 2.3 (Table 16). Two threats among the three which were identified were classified as major threats and those two threats were also considered as highly relevant with a weight of 0.15 for each factor (Table 16). The threats received a total score of 0.5 (Table 16). The total weighted score for the external factors was resulted as 2.80 (Table 16).

Table 16. External factors evaluation matrix

	External factor	Weight	Rating	Weighted score
Opportunities	Ability to hire foreign nationals who could work for longer periods	0.13	4	0.52
	Constant development of the newly introduced harvesting system by GTL – Europe	0.05	3	0.15
	Ability to expand the farm in a way that labour cost is reduced i.e., using advanced technology	0.05	3	0.15
	Ability to attract more customers due to the wide variety of mushrooms and the quality of them	0.17	4	0.68
	Development in information technology	0.20	4	0.8
	Total	0.60		2.3
Threats	Production risks (due to spreading of diseases and wrong harvesting techniques)	0.15	1	0.15
	Low quality of the substrate and casing soil due to a problem of the natural raw material used	0.10	2	0.20
	High production costs	0.15	1	0.15
	Total	0.40		0.5
	Total weighted score	1.00		2.80

### 3.5 SWOT analysis

Table 17. SWOT analysis

<p><b>Strengths (S)</b></p> <p>S1. Have introduced new technology within the farm (site C)</p> <p>S2. Having growers with long-term experience</p> <p>S3. Having a long-term and large customer base</p> <p>S4. Receiving compost and substrate from reliable companies</p> <p>S5. Having well experienced harvesting managers and supervisors to assist</p> <p>S6. Possibility of having training programs for the pickers</p> <p>S7. Possibility of investing in modern technology and maintaining the resources which are existing</p>	<p><b>Weaknesses (W)</b></p> <p>W1. Mushroom growing requires natural raw material</p> <p>W2. Having too many varieties to sort</p> <p>W3. Constant change in pickers</p> <p>W4. Technical problems with the new system and the lorries</p> <p>W5. No constant, long-term analysis of the performance of the supervisors and the pickers</p>
<p><b>Opportunities (O)</b></p> <p>O1. Ability to hire foreign nationals who could work for longer periods</p> <p>O2. Constant development of the newly introduced harvesting system by GTL - Europe</p> <p>O3. Ability to expand the farm in a way that labor cost is reduced i.e., using advanced technology</p> <p>O4. Ability to attract more customers due to the wide variety of mushrooms and the quality of them</p> <p>O5. Development in information technology</p>	<p><b>Threats (T)</b></p> <p>T1. Production risks (due to spreading of diseases and wrong harvesting techniques)</p> <p>T2. Low quality of the substrate and casing soil due to a problem of the natural raw material used</p> <p>T3. High production costs</p>

Table 17 shows the designed SWOT incorporating the data from the IFEM (Table 15) and EFEM (Table 16). There are 7 strengths, 5 weaknesses identified within the company, 5 external opportunities and 3 external threats in the external environment of the company to be discussed (Table 17).



The S-O, S-T, W-O and W-T combinations were analyzed, and the best (alternative) strategies were suggested to incorporate for long-term planning of the farm.

*Suggested strategies (SS)*

SS1: Long-term analysis of the quality of the substrate and casing soil along with the production rates.

SS2: Analysis of the improvements and performance of the pickers over time.

SS3: Employing pickers who could work for a long-term and providing compulsory training programs at least twice a month.

SS4: Introducing effective communication system:

- between the central controlling system and the production site at site C, so that the supervisors don't have to walk a long distance during their work to change a setting
- between the pickers and the packers (would be easy for the packer to sort different varieties at once and to prepare punnets)

SS5: Buying/ replacing lorries (sites A/B) and taking quick action for the technological problems so that the costs (time, money) won't be too high.

### 3.6 Quantitative Strategic Planning Matrix (QSPM)

Table 18. QSPM

Key factor	Weight	SS1		SS2		SS3		SS4		SS5	
		AS	TAS	AS	TAS	AS	TAS	AS	TAS	AS	TAS
O1	0.13	1	0.13	4	0.52	4	0.52	1	0.13	4	0.52
O2	0.05	1	0.05	4	0.20	4	0.20	4	0.20	4	0.2
O3	0.05	1	0.05	1	0.05	3	0.15	3	0.15	4	0.2
O4	0.17	3	0.51	1	0.17	2	0.34	4	0.68	1	0.17
O5	0.20	4	0.80	4	0.80	3	0.60	4	0.80	1	0.2
T1	0.15	1	0.15	4	0.60	4	0.60	2	0.30	1	0.15
T2	0.10	4	0.40	2	0.20	2	0.20	1	0.10	1	0.1
T3	0.15	3	0.45	4	0.60	3	0.45	3	0.45	4	0.6
S1	0.05	3	0.15	4	0.20	2	0.10	3	0.15	3	0.15
S2	0.05	3	0.15	4	0.20	3	0.15	4	0.20	1	0.05
S3	0.10	3	0.30	3	0.30	3	0.30	3	0.30	1	0.1
S4	0.10	4	0.40	1	0.10	2	0.20	2	0.20	1	0.1
S5	0.10	4	0.40	4	0.40	3	0.30	3	0.30	1	0.1
S6	0.05	1	0.05	4	0.20	4	0.20	3	0.15	1	0.05
S7	0.05	1	0.05	3	0.15	1	0.05	3	0.15	3	0.15
W1	0.14	4	0.56	3	0.42	2	0.28	1	0.14	1	0.14
W2	0.05	3	0.15	3	0.15	4	0.20	3	0.15	1	0.05
W3	0.20	2	0.40	2	0.40	4	0.80	3	0.60	1	0.2
W4	0.03	1	0.03	1	0.03	1	0.03	1	0.03	3	0.09
W5	0.08	4	0.32	4	0.32	3	0.24	1	0.08	1	0.08
STAS			5.50		6.01		5.91		5.26		3.40
Priority			3		1		2		4		5

Attractiveness scores (AS): 1 = not attractive, 2 = somewhat attractive, 3 = reasonably attractive, and 4 = highly attractive. SS: Suggested strategies, TAS: Total Attractiveness score, STAS: Sum of total attractiveness scores

The AS were assigned according to the scoring system followed by Ommani (2011) (Table 18). It shows how important or attractive each factor is to the suggested strategy (SS). Ranking 1 was assigned when it wasn't attractive, ranking 2 when it was somewhat attractive, ranking 3 for reasonably attractive and ranking 4 for highly attractive. The TAS was found by multiplying the weight for each key factor by the AS. TAS showed the relative attractiveness of each suggested strategy to each of the key factors. The sum of total attractiveness scores (STAS) was obtained by adding the TAS in each strategy (SS) column. Finally, the STAS indicated the most attractive alternative strategy and consequently the priority levels of them. The suggested strategies were prioritized as follows based on the findings (Table 18):

1. SS2: Analysis of the improvements and performance of the pickers over time.
2. SS3: Employing pickers who could work for a long-term and providing compulsory training programs at least twice a month
3. SS1: Long-term analysis of the quality of the substrate and casing soil along with the production rates.
4. SS4: Introducing effective communication system within the farm.
5. SS5: Buying/ replacing lorries (sites A/B) and taking quick action for the technological problems so that the costs (time, money) won't be too high.

## 4 DISCUSSION

### 4.1 Analyzing theories of scientific management

Fredrick Taylor's theories of scientific management is a fundamental guideline for industries to realize their maximum potential in terms of work simplification. The scientific management theory focuses on the key issue of "increasing labor productivity" and proposes essential management and organizational theories, such as norm of work (creating a standardized, scientific method), specialized management functions, piecework wage system, and the principle of "division of labor" (Kendall, 1913). This approach is expected to result in higher wages, higher profits, and thereby, to establish greater peace between companies and employees (Caldari, 2007). However, it is unlikely that concepts of work simplification will have a direct impact on product quality or uniformity (Engene, 1946). Scientific management, according to Frey (1913) and Thompson (2003), is more concerned with the quantity of production than with the quality of that production, and it views people as an instrument for production rather than human beings. They believe on the same concept put forwarded by Hardin (1947), that the cost of production should be reduced by eliminating unnecessary labor and to enhance employee working conditions, such as providing decent and sufficient light, clean air, sanitary conditions, and safe machinery.

As a response to low labor efficiency and the growth of labor conflicts within the industries (as workers believed they worked more but were paid less), Taylor suggested standardizing the work procedures so that a "reasonable daily work" could be achieved (Su, 2017). It should be created in a way that no worker should be put into a position of physical exhaustion (Frey, 1913). Major risk in

implementing new approaches is failing to find a way to change the management teams and workers' psychological attitudes and behaviors (Blake and Moseley, 2011, Mogensen, 1952). Jhon Commons (an American institutional economist) believes that extreme standardization of operations could exacerbate conflicts between the employees and the employers (Frey, 1913). Scientific selection is required to identify the appropriate individual for the job, thereby saving the company resources by releasing a worker who does not meet the company's expectations (Huang et al., 2013). Lack of education among workers is identified as one of the major challenges in introducing and adopting the scientific methods of management (Huang et al., 2013). Thompson (2003) identified that following the principles of management is more important than following the piecework wage system. If the farm is poorly planned, increased operational efficiency will not result in maximum earnings (Engene, 1946). Taylorism has become an expensive management approach to implement and operate due to extensive task allocation (division of labor), and thereby resulting in middle-class jobs (Huang et al., 2013). Due to extreme task allocation, lack of flexibility has resulted making it a huge challenge for the workers (Huang et al., 2013, Strauss, 1985). Blake and Moseley (2011) identifies *dehumanization of workers* (meaning that they are not given their space to think or excel on their own) as major challenge in Taylorism. Hence, it requires modification in the theories by Taylor when putting into practice.

## 4.2 Analyzing work simplification strategies in mushroom farming

Technologically advanced mushroom harvesting systems have been developed in the world as there is a huge labor scarcity in this field of agriculture (Grift, 2007) resulting in increase of cost of labor. Computerized systems are extensively used to monitor the production phases (Yaghoubi et al., 2013, Suresh et al., 2021), replacing human labor to reduce the net farm costs (Young and Hardin, 1943). Investing in new equipment, technology, and qualified staff significantly increase the productivity (Kitaw and Belachew, 2007). However, huge investments could be challenging for some of the local industries. Therefore, Kitaw and Belachew (2007) suggests to eliminate the productivity barriers (i.e., inefficient work methods, loss of energy, materials and manpower) as much as possible and to strengthen the positive productivity factors which are currently existing in the company (i.e., using tools for work simplification: e.g. improving recipe settings).

The tilting shelf system introduced by GTL- Europe is immensely supportive in picking the “right” mushroom easily as the working area of the bed can be examined well before picking compared with the traditional system of harvesting with fixed shelves (Van Dieten, 2021d). Allowing the pickers to harvest by both hands is another major advantage of this system (Van Dieten, 2021d). This increases the output by roughly 40% compared to when one hand is used alone (Young and Hardin, 1943, Hardin, 1947). A better hand-eye coordination is achieved by keeping them close together and incorporating a rhythmic movement that make harvesting easier (Young and Hardin, 1943, Hardin, 1947, Gerwen, 2021). Further, ergonomics wise it is seen that this method is far better than the traditional system of picking (Van Dieten, 2021d). Additionally, customizing recipe

settings for each day of the flush aids in managing picking speed, and thereby avoiding over picking. Whereas, there is no control over the picking speed in the traditional system. Van Dieten (2021d) identifies that the lost time in the harvesting system is due to the packers. Therefore, arranging scales, crates and punnets accordingly is necessary (Young and Hardin, 1943). It is crucial to emphasize, however, that the technically advanced system requires skilled labor to be profitable when compared to the traditional system with highly experienced pickers.

Robotic harvesting systems in the mushroom industry can be tremendously advantageous because they can work 24 hours in a dark, damp environment where humans do not prefer (Yaghoubi et al., 2013). Developed robotic harvesting programme identifies a set of tasks which are covering mushroom location, sizing, selection, picking, grading, trimming, and transfer (Reed et al., 2001). Kashkoush and Avigad (2019) identifies the importance of decision support system that aids in the process of further innovation as the decision-making component is crucial in an automated harvesting system. The robotic system includes an automatic suction cup shifting mechanism to allow natural variations in mushroom sizes, as the optimal suction on the vacuum cup is critical because the mushroom's surface can be easily damaged (Chua et al., 2003). As the quality is a major factor considered, using the suction cup makes it difficult for harvest (Noble et al., 1997b). Coles et al. (2021) identifies that the spreading of diseases like green mould or sciarid flies can be reduced significantly with the introduction of new technology as it mitigates the human-substrate contact. However, Jarvis (1997) explains, with adequate financing, automated mushroom cultivation can be popular in the coming years. While this aids in achieving

objectives in terms of economic, food safety, and environmental concerns in the future (Tillet, 2003).

#### 4.3 Analyzing methods used in time-motion studies

Time motion studies are conducted to find ways to improve the productivity and efficiency of a certain task (Lopetegui et al., 2014). Continuous and work sampling techniques are quantitative data collection methods done by direct observation. Thereby, the results are more accurate, reliable, and valid than other types of data collection methods i.e., self-reports where a direct observer is not involved (Pinzke, 1997). As a downside, in real-time direct observations, the person subjected to observation might feel disturbed and it is also possible that he/she tries to improve the performance than their normal rate (this phenomenon is referred to as “Hawthorne effect”) (Franke and Kaul, 1978). Work sampling is challenging as it requires quick judgements about the behaviour of several workers at once whereas continuous sampling requires detailed data of workers individually (Finkler et al., 1993). It is evident that continuous sampling is more accurate than work sampling based on several studies (Burke et al., 2000, Pizziferri et al., 2005, Lopetegui et al., 2014, Zheng et al., 2011, Finkler et al., 1993, Pinzke, 1997). The work-sampling approach has the potential to be flawed as the evaluation can be inaccurate due to systematic biases introduced during the sampling process (Finkler et al., 1993). If continuous sampling is used, it is possible to get an insight of the whole process of the work although it consumes a lot of time and is highly labor-intensive as it requires one-on-one observation (Wirth et al., 1977, Finkler et al., 1993, Toh et al., 2014). On the other hand, work sampling only gives an insight of parts of the work process in a less costly way



(Wirth et al., 1977). Work sampling method is more applicable for less frequent tasks, as the number of observations required for the study is less and thereby gaining the advantage of this TMS method (Barnett, 2008, Auernhammer, 1979, Lopetegui et al., 2014). Unfortunately, the study from Lopetegui et al. (2014) explains that a major proportion of researchers who have carried out work sampling with an external observer have always used fixed time intervals which in turn reduces the accuracy of the results. However, the detailed information gathered in time-motion studies is useful in assessing and analyzing the influence of information systems on the task (Pizziferri et al., 2005). Continuous sampling being the most efficient TMS method and following the standardized method proposed by Zheng et al. (2011) would give more accurate results according to Lopetegui et al. (2014). Due to the extensive mobile work in farming, direct data collection methods are not suitable according to Pinzke (1997). It is evident in mushroom harvesting the picker is not extensively mobile and has frequent tasks. Therefore, continuous sampling method is more suitable and was used in this study.

In order to mitigate the collection of inaccurate results due to inconsistencies in observation, video registration is proposed where the motions are captured and analyzed repeatedly during a high working pace (Matthew and Rodgers, 1955, Burdorf and Laan, 1991, Kilbom et al., 1986). Although Zheng et al. (2011) argues that standard observer training has a greater potential in reducing most of the inaccuracies.

#### 4.4 Analyzing the time-motion studies of the farm

The TMS identifies the most time-consuming activities the pickers (at sites A/B) and packers (at site C) engage other than in their main task. Pickers at the traditional farm have more responsibilities than those at the technologically equipped farm. This concludes that a major portion of their picking time is lost due to other activities involved. The improvements resulted in a higher overall picking efficiency at sites A/B and C.

Improvements were made at sites A/B in the tasks of bringing and loading new crates to the lorries, exchanging information and walking (Table 1). Time taken for activities i.e., crate changes, unloading and loading depends on the experience of the pickers and their capability. Hardin (1947) suggests shortening walking distance to the empty punnets and crates, having more supervision while picking, assigning smaller groups for each supervisor, and providing clear instructions on what to pick can have a greater efficiency. It was seen that pickers tend to walk outside leaving their job during the working hours. Problems develop as a result of lack of supervision on the pickers and a breakdown in communication between the supervisor and the picker, which leads to pickers leaving during working hours (Namugenyi et al., 2019). Further, Benos et al. (2020a) and Benos et al. (2020b) identifies ergonomic problems could be a reason for the issue stated above. It can be mentioned that verbal communication was challenging, and it is questionable if their conversations were work related or not. Further, it was identified introducing a new work method requires much effort. The study which was done after implementing the strategies showed a significant change in the average time taken for transporting and loading new

crates to the lorries (Table 3). Although some results did not show a significant change, it is evident of an improvement of the average times (Table 1 and Table 2).

At site C, reasons were identified for the waiting time of the packers upon observation of the pickers. Pickers getting down from the lorry to tilt the shelves, growth of mushrooms not being even resulting in not many mushrooms to be picked in a certain area of the bed, changing the direction of the lorry, the pick belt moving too slow, and the experience of the pickers were the reasons. After the recipe settings were changed, with pickers and packers gaining more experience and identified changes in growing, resulted in a less average waiting time. But compared with the other activities, the percentage was greater (Table 9). The pickers and the packers here in this system could also face ergonomic problems due to long picking hours, even though problems with mushroom harvesting is comparatively less when compared with other types of crops (Benos et al., 2020b). On the other hand, Benos et al. (2020b) has mentioned that the introduction of machinery wouldn't eliminate the health problems completely. Musculoskeletal disorders are considered to be one of the major factors leading to work time loss and it is important to educate the workers of inappropriate postures during work (Bon and Daim, 2010, Houshyar and Kim, 2018). This could be further mitigated by conducting regular training programs as explained by Krystosik-Gromadzińska (2018) and Subramanian et al. (2017). As a result of higher picking efficiency, it could be stated that the time taken for crate changes further increased (Table 2 and Table 9).

Direct observation of pickers and packers must have led to psychological issues as they were not comfortable when obtaining results, thereby leading to minor errors in the results obtained. However, the workers showed a positive response with time during the study. This issue could have been managed better if the management made them aware of it (Jacobson, 1969). Hence, the results obtained by this study stipulates the areas that need more concern when designing a new harvesting system.

#### 4.5 Analyzing weights of champignons, pick rates and efficiencies

Average weights of champignons are mainly dependent upon the growing techniques, quality, picking management and customer requirements (Haegens, 2021). El Hage et al. (2021) argues that champignons are ready for harvest when the caps are well rounded, with a completely intact partial veil. Picking mushrooms unnecessarily (over picking or picking too small mushrooms) results in decrease in the weights harvested and ultimately increase in picking costs (Straatsma et al., 2013, Rowley, 2009). It will further lower the yields in the subsequent flushes and will reduce the quality (Straatsma et al., 2013).

The outliers resulted in the weights of white 30 mm champignons maybe due to an error in packaging (such that champignons less than 30 mm were added to the punnet) (Figure 9). It is not always possible to pack the exact size of champignons due to problems in the availability of certain size classes of brown champignons (e.g., 60 mm champignons in the second flush), causing outliers (Figure 12) (Van Dieten, 2021c). Weight distribution of canning quality and 60 + mm champignons are broad as the size of the harvested champignons are not

specific in size (Van Dieten, 2021c). Therefore, the SD (Figure 8 and Figure 11) and the range of distribution of weights with error bars are high (Figure 9 and Figure 12). Moreover, the weights are not constant throughout the flush and between each flush as it's a natural growing process (Haegens, 2018). Usually, an average weight of a flush 2 champignon weighs less than a flush 1 champignon (Figure 10 and Figure 13).

Some of the features of canning mushrooms are,

- I. They are not having their specific color (bright white or brown)
- II. They have casing material on them
- III. They have blotches
- IV. Have open caps and broken stems where they weigh comparatively less than a champignon of the same cap diameter (Diamantopoulou and Philippoussis, 2015, Noble et al., 1997a).

Harvesting more of the canning quality champignons can result in lower production rates (kg/hour harvested). Delaying harvesting times results in frequent cap opening (Braaksma et al., 1999). Mushroom size at harvest is found out to be significantly correlated with the extent of the cap opening (Braaksma et al., 1999). It is essential that mushrooms need to be picked just before it opens under the cap unless that could lead to spread of diseases (Jarvis, 1997).

This research identifies the picking efficiency and pick rates (by the database) are dependent on the average weights of the champignons (regardless of size class). It is also noted that, instructions on what to pick (Gerwen, 2021), customer requirements (Reed et al., 2001) and quality of the mushrooms (Diamantopoulou and Philippoussis, 2015) are also factors that affect the picking efficiency. Pick rates are normally low on the first and the last day of a first flush, and the last day

of a second flush due to the growth of low quality mushrooms (Diamantopoulou and Philippoussis, 2015). It should be noted that the pick rates (by observation) and weights of champignons used in this study were obtained during the months May-July 2021. Therefore, the picking efficiencies may not be the same if a study is conducted at present.

Mushrooms are a crop which is challenging to grow as their growth is rapid (Yaghoubi et al., 2013). It is estimated that they double in size every 24 hours (Rowley, 2009, Diamantopoulou and Philippoussis, 2015). It is important to stagger pinheads (growth of the mycelium appear as pinheads) so that there are sufficient mushrooms to be picked over following days (this allows to follow the harvesting system: “separation”) instead of them being ready to be picked in one day (Rowley, 2009, Van de Vegte et al., 2017). Diamantopoulou and Philippoussis (2015) has explained that graze picking (picking multiple times a day) is the optimal way to improve the retail quality, color, shelf-life, longer flush and higher productivity. Better yields are expected when there is a compact structure of the casing soil in the vegetative phase with sufficient water (Visscher, 1975). The quality and shelf-life of the mushrooms can be improved by trimming the stems (Beelman et al., 1993).

When it comes to direct labor, it's critical to optimize the amount of time spent per flush; otherwise, non-value-added activities will deplete the efficiency (e.g., moving or waiting) (Rowley, 2009). Furthermore, getting the pickers to employ proper harvesting procedures is a challenge, and it takes time for them to adjust to the system (Van Dieten, 2021b). Experience of the pickers, packers (at site C), harvesting managers, growers are very important apart from receiving

quality substrate and casing soil to maintain reasonable production rates in the long-term.

#### 4.6 Analyzing tools used in strategic management

IFEM and EFEM are strategy formulation tools that are used to analyze internal (strengths, weaknesses) factors and external (opportunities, threats) factors, in a business (David et al., 2009a). It is beneficial to quantify the factors mentioned in order to avoid misinterpretation and misunderstanding of the final decisions (Wardhani and Dini, 2020). The results of traditional SWOT analysis is based only on qualitative estimation, whereas the IFEM and EFEM are based on a quantitative methodology (Lee and Lin, 2008, Hadighi and Mahdavi, 2011). Analyzing the internal and external factors quantitatively might improve the accuracy of the study, on the contrary, it is up to a certain extent in situations where uncertainty plays a role in the competitive environment (Bhattacharjee and Dey, 2015). SWOT analysis is highly regarded for its simplicity and the usefulness in identifying the factors affecting the growth and development of a company (Pickton and Wright, 1998, Oreski, 2012, Benzaghta et al., 2021, Mandrazhi, 2021). On the other hand, over simplicity of the SWOT analysis is often criticized as the factors expressed are too general and thereby, the results are often inaccurate or superficial (Oreski, 2012, Lee et al., 2020). SWOT analysis incorporates the internal and external factors of a specific time but in reality, the environment is changing at a rapid pace. Therefore, a question will arise if the results are still valid (Issayev et al., 2018, Tang et al., 2018). Moreover, analyzing factors in a non-critical manner without clear prioritizing may result in erroneous conclusions, resulting in bad management decisions and actions (Pickton and

Wright, 1998, Pickton and Wright, 1997). Further, limitations of the SWOT are, factors being missed out or disagreement over factors i.e., to which category it belongs to and the factors only representing opinions and not facts (Pickton and Wright, 1998, Glaister and Falshaw, 1999). Misrepresentation of the SWOT inputs results in erroneous conclusions when it is performed only by few people (Teoli et al., 2020). Pickton and Wright (1998) believes that it is important in engaging managers at all levels of the business for it to be a group tasks which is beneficial for the organization's performance and the individuals. According to Namugenyi et al. (2019), limitations in the SWOT analysis could also occur due to the over complexity of organizational or business structures. This thesis focus on the SWOT analysis to introduce alternative strategies thereby using QSPM for prioritization.

QSPM is a great tool used for integrating and prioritizing important internal, external, and competitor data objectively, for developing a strategic plan (David et al., 2009b, Wijayati et al., 2019). In the QSPM, an unlimited number of strategies can be evaluated at once, and they can be evaluated sequentially and simultaneously (Zulkarnaen and Sutopo, 2013). Downsides of the QSPM are, that it is based on how good the formulated data already is. It requires assumptions based on assumptions and intuitive reasoning, it assigns attractiveness scores requiring good judgment and that the total attractiveness score could be so close that its challenging to make a final decision (David et al., 2009b, Wardhani and Dini, 2020). Overall, the limitations of QSPM are supposed to be lower than its strengths as objective decisions are taken on the alternative strategies (David et al., 2009b).



Studies have found out that combination of other quantitative models to SOWT analysis i.e., Analytic Hierarchy Process (AHP) (Görener, 2012, Shrestha et al., 2004, Oreski, 2012, Kurttila et al., 2000), Strategic Position And Action Evaluation (SPACE) matrix (Wijayati et al., 2019, Wardhani and Dini, 2020), Political, Economic, Social, Technological, Legal and Environmental (PESTLE) framework and five forces model (Wu, 2020) aids to improve the overall quantitative results and to support in the strategic planning process.

#### 4.7 Analyzing results by IFEM, EFEM, SWOT and QSPM

A fundamental strength of RPZ is that it receives substrate and compost from the most reputable enterprises in Europe. Furthermore, because Germans are more inclined to consume regional products, there is a significant demand for products by RPZ. As a result, company is having a long-term customer base. Harvesting managers and supervisors with experience know how to allocate pickers to specific areas of the growing halls and which day of the flush they should work on. One of the major flaws is that the picks are always changing. As a result, they must provide detailed instructions to the new pickers, and it will take several months for them to become accustomed to the system (Hardin, 1947). This has a direct impact on production rates, and the company will have to invest heavily on training programs. The ideal solution would be to hire pickers who are willing to work for longer periods of time. The substrate and casing soil are made from natural raw materials which affects the consistency of the quality and production in mushroom cultivation. A key flaw in mushroom cultivation is that the quality and production levels do not remain consistent over time. Overall, the farm receives a total weighted score of 2.53 (Table 15) for the internal factors on a

scale of 1 to 4, meaning that there is more room for improvement (David et al., 2009b).

According to the EFEM (Table 16 ), it is proved that certain areas of information and technology within the company can be improved because it is already a viable option. At site C, communication is a crucial factor between the pickers and packers, as well as between the central controlling system and the harvesting managers resulting in fewer interruptions to the workflow, and the decision-making process would be aided (Namugenyi et al., 2019). In this instance, using a two-way radio would be a possibility. Uncertainty about the production levels upon the quality of natural raw materials will be reduced if output levels are estimated beforehand to a certain extent. Furthermore, if the personnel is hired for the long term and is well experienced, production risks may be reduced. Pickers' lack of understanding regarding adequate hygiene standards results in spread of infections by pests such as phorid flies and mites (Geels et al., 1988). The total weighted score for the external factors was found out to be 2.80 which is also above average and can be improved further as the range is between 1 and 4 (David et al., 2009b).

The QSPM prioritized the suggested strategies based on the SWOT analysis, which demonstrated that studying or analysing the performance of pickers over time and hiring pickers who are willing to work for a long time are significant. Gathering this data would aid in making decisions regarding the future of the company and the reasonable actions that should be taken. However, at this point, it is challenging to determine which strategy would yield better results or how these strategies would influence production rates and to what extent.

## 5 CONCLUSION

This study contributes to the improvement of the production levels of a commercial *Agaricus bisporus* farm by conducting a time-motion study, by empirical data collection followed by a SWOT analysis incorporating IFEM, EFEM and the QSPM. The results of the time-motion study showed that the time taken for crate changes was high at both farms. This might be an important finding for the future developments of harvesting systems in the mushroom industry. Constant supervision, clear communication, improving internal logistics were ways to improve the overall picking efficiency at the traditional farm (Sites A/B). At the technologically improved farm (site C), it was seen that the waiting time was the major bottleneck affecting its picking efficiency. Picking efficiency is dependent upon the experience of pickers and packers (at site C), growing techniques (affecting the number of pins), weight of the mushrooms and picking management.

It is believed that incorporating quantitative strategic management tools to the SWOT would enhance the results. To improve production rates, experience of the pickers is highly beneficial and the QSPM results showed that analyzing the performance of the pickers is the most important long-term strategy that can be implemented.

Apart from the growers and harvesting managers, the pickers are the greatest asset in mushroom farming as picking the right mushroom is a very valuable decision when it comes to efficiency of the farm. Therefore, skilled labor is required specially at site C to make it profitable. It is important to establish the best possible working environment for them, to gain their trust and motivation for

the job. Constantly educating the workers about harvesting techniques is beneficial and would motivate them to do their work better. Calculating the picking efficiency over a long period of time would give more accurate results for the farm. It is important to avoid anything which interrupts the sequence of the production process that leads to losses at a rapid rate. Therefore, it would be beneficial to invest time in studies regarding workflow to improve the work methods of the company. Further, scientific research in various strains of champignons, growing techniques and picking management would be extremely beneficial to the mushroom industry in terms of increasing output rates in a sustainable manner.

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## DECLARATION

“I hereby declare that I have written this thesis independently and without outside help and that no sources or aids other than those indicated have been used. All passages in the thesis which have been taken from other people's works in terms of wording or meaning are always indicated with the source. This thesis has not yet been submitted to any examination authority in the same or a similar form.”

Kleve, 22.12.2021

Osuri Ratnayake

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## APPENDIX A

Average weights obtained per size class throughout the 1<sup>st</sup> and 2<sup>nd</sup> flush at sites A/B

Sites A/B		Strain 737				
Flush 1		Avg. weight (grams)				
Room	30 ±5mm	40 ±5mm	60 ±5mm	60+ mm	Konserve	
6	10.75	20.08	58.08	71.82	49	
10	10.27	20.52	48.28	69.64	35.3	
12	10.15	22.96	53.80	70.25	58.3	
13	9.72	20.83	57.76	79.57	48.1	
15	9.93	21.89	55.78	74.91	20.9	
16	10.50	20.30	53.97	70.73	57.9	
18	13.60	22.13	53.46	68.34	55.8	
19	10.32	20.34	56.84	65.78	49	
20	9.86	19.54	48.98	75.10	50.1	
1	9.43	19.69	52.97	72	50.8	

Flush 2		Avg. weight (grams)				
Room	30 ±5mm	40 ±5mm	60 ±5mm	60+ mm	Konserve	
6	7.80	19.00	50.64	71.00	50.34	
10	12.60	17.80	47.10	55.60	40.21	
12	8.80	19.77	50.14	68.45	40.56	
13	7.98	18.56	49.23	57.98	38.71	
15	8.10	19.34	50.89	64.78	28.94	
16	8.00	17.98	52.00	73.15	47.98	
18	7.21	18.32	49.89	74.12	53.00	
19	7.90	17.69	49.00	68.88	55.00	
20	8.15	18.34	51.34	72.11	40.00	
1	7.59	18.98	52.00	73.67	59.00	

## APPENDIX B

Average weights obtained per size class throughout 1<sup>st</sup> and 2<sup>nd</sup> flush at site C.

Site C					
Strain: Heirlooms					
Flush 1	Avg. weight (grams)				
Room	30 ±5mm	40 ±5mm	60 ±5mm	60+ mm	Konserve
43	10.8	21.11	58.65	66.92	35.7
44	10.34	22.22	53.35	68.52	53
40	10.02	19	50.47	75.57	33.8
41	9.75	18	48.81	82.66	41.6
47	10.08	19.43	49.87	72.45	53
48	12.45	20.03	51.11	83.45	31.9
35	11.34	18.45	48.34	87.23	32.7
34	12.45	15	50.65	78.96	57.3
31	11.56	14.23	52.1	80.85	56
32	10.54	16	48.34	75.89	31.38

Flush 2	Avg. weight (grams)				
Room	30 ±5mm	40 ±5mm	60 ±5mm	60+ mm	Konserve
43	8.5	18.2	53.7	71.1	33.6
44	8.8	16.4	50.87	68.33	37.8
40	8.65	17.3	52.28	69.12	27.6
41	8.34	16.46	37	59.23	28.7
47	7.89	15.43	52	52.04	33.2
48	7.45	16.32	35.23	45.4	55.9
35	8.37	14.34	48	52.32	45.8
34	7.45	16	42.12	48.02	49
31	8.23	17.1	32.43	45	59
32	7.89	14.54	31.21	43.2	22.68

## APPENDIX C

### Sites A/B

Flush	Size class (no. of champignons = total g per size/ avg weight per size)					Total no. of champignons	total grams harvested	Avg weight/champignon
	30 mm	40 mm	60 mm	60+ mm	canning			
1		12600.00	8888.89	26794.44	1382.98	49666.31	2738800	55.14
1			46311.11	40088.89	3829.79	90229.79	5567200	61.70
1		9142.86	43629.63	31105.56	8617.02	92495.06	5192600	56.14
1		1266.67	42022.22	18161.11	12978.72	74428.72	4213400.00	56.61
1		1200.00	15725.93	5066.67	21861.70	43854.29	2266700.00	51.69
1		857.14	88.89		691.49	1637.52	55300.00	33.77
1		31133.33	7940.74	9644.44	1117.02	49835.54	1829500.00	36.71
1		11580.95	59911.11	21277.78	3351.06	96120.91	5167900.00	53.76
1		14095.24	86555.56	29366.67	7287.23	137304.69	7426900.00	54.09
1		79180.95	287892.59	43688.89	57446.81	468209.24	23054600.00	49.24
1		48952.38	271592.59	54608.33	25957.45	401110.75	20845800.00	51.97
1		96419.05	256211.11	32130.56	23351.06	408111.78	19271100.00	47.22
1		71133.33	248737.04	54772.22	33351.06	407993.66	20436700.00	50.09
1		94057.14	232962.96	54116.67	24946.81	406083.58	19624100.00	48.33
1	27120	176857.14	468133.33	110347.22	106170.21	888627.91	42199400.00	47.49
1	15760	88266.67	277933.33	100104.17	20957.45	503021.61	25212100.00	50.12
1		14628.57	87924.07	23704.17	3457.45	129714.26	6924300.00	53.38
1		18590.48	84544.44	18850.00	4574.47	126559.39	6528000.00	51.58
1		79180.95	287892.59	43688.89	57446.81	468209.24	23054600.00	49.24
1	15860	93704.76	279606.67	108458.38	21250.09	518879.89	26032917.00	50.17
<b>Average weight/champignon</b>								<b>50.42</b>



Flush	Size class (no. of champignons = total g per size/ avg weight per size)					Total no. of champignons	total grams harvested	Avg weight/champignon
	30 mm	40 mm	60 mm	60+ mm	canning			
2				82.35	777.78	860.13	40600.00	47.20
2	5400	34189.47368	11936	1326.47	4722.22	57574.17	1592300.00	27.66
2	18300	41810.52632	89276	391.18	4888.89	154666.59	5651200.00	36.54
2		40905.26316	94196		14777.78	149879.04	6152000.00	41.05
2		17684.21053	27588		7277.78	52549.99	2042900.00	38.88
2				652.94	1944.44	2597.39	131900.00	50.78
2		14421.05263	7540	3211.76	1666.67	26839.48	944400.00	35.19
2	17700	7578.947368	49798	1338.24	3611.11	80026.29	3029000.00	37.85
2		13115.78947	97944	3273.53	8444.44	122777.76	5749000.00	46.82
2		17031.57895	33200	323.53	5111.11	55666.22	2235600.00	40.16
2	51100	122673.6842	193774	3041.18	43277.78	413866.64	14582600.00	35.24
2	17100	23010.52632	206960	2011.76	70000.00	319082.29	15002000.00	47.02
2	52450	124200	194538	3188.24	43333.33	417709.57	14673100	35.13
2	20100	101673.6842	345380	31542.65	93277.78	591974.11	25704000.00	43.42
2		49557.89474	209508	10535.29	56500.00	326101.19	14675900.00	45.00
2	10650	14442.10526	234984	17682.35	34666.67	312425.12	14871200.00	47.60
2	2100	55115.78947	176840	2611.76	12500.00	249167.55	10646100.00	42.73
2	23900	108821.0526	196368	6070.59	13051.47	348211.11	13377500.00	38.42
2	23901	108784.2105	196500	6389.71	19475.56	355050.72	13394010.00	37.72
2		33868.42105	9930	1182.35	4497.78	49478.55	1422800	28.76
								<b>40.16</b>

## APPENDIX D

### Site C

Flush	Size class (no. of champignons = total g per size/ avg weight per size)					Total no. of champignons	total grams harvested	Avg weight/champignon
	30 mm	40 mm	60 mm	60+ mm	canning			
1	2360.00	84444.44	388213.73	701.30	27777.78	503497.25	22622900	44.93
1	760.00	19466.67	50743.14	701.30	1944.44	73615.55	3087400	41.94
1		23444.44	149858.82		5388.89	178692.16	8307300	46.49
1		24733.33	141545.10		12222.22	178500.65	8214000	46.02
1		16088.89	39482.35		7111.11	62682.35	2623200	41.85
1	1200.00	711.11	4639.22		888.89	7439.22	301400.00	40.52
1	760.00	9066.67	36052.94	701.30	1388.89	47969.80	2126000.00	44.32
1		12888.89	107184.31		3944.44	124017.65	5875900.00	47.38
1		14166.67	52138.46		6444.44	72749.57	3256200.00	44.76
1	400.00		1945.10		222.22	2567.32	113200.00	44.09
1		10400.00	14690.20		555.56	25645.75	961400.00	37.49
1		10577.78	42674.51		1444.44	54696.73	2431800.00	44.46
1		10566.67	88384.31		5777.78	104728.76	4957800.00	47.34
1		36355.56	152111.76	1740.85	28430.23	218638.40	9758200.00	44.63
1		36800.00	201674.51	1622.54	12906.98	253004.02	11618000.00	45.92
								<b>44.14</b>

Flush	Size class (no. of champignons = total g per size/ avg weight per size)					Total no. of champignons	total grams harvested	Avg weight/champignon
	30 mm	40 mm	60 mm	60+ mm	canning			
2		28500	29725.5814	5216.36	8974.36	72416.30	2371100.00	32.74
2		27562.5	28186.04651	5434.55	5756.41	66939.50	2176400.00	32.51
2	1234.625		31220.93023	5178.18	461.54	38095.28	1655177.00	43.45
2		10587.5	36944.18605		2051.28	49582.97	1838000.00	37.07
2		20725	35944.18605		3076.92	59746.11	2016400.00	33.75
2		4875	22237.2093		2564.10	29676.31	1134200.00	38.22
2		31400	130837.2093	1396.36	8076.92	171710.50	6520200.00	37.97
2		32650	93402.32558		8461.538462	134513.86	5310300.00	39.48
2	1225	20562.5	104572.093		1666.666667	128026.26	4900400.00	38.28
2		10887.5	127060.4651	305.45	5576.923077	143830.34	5872100.00	40.83
2	1050	147425	156665.1163		10448.71795	315588.83	9511300.00	30.14
2		128100	145186.0465		33974.35897	307260.41	9617600.00	31.30
2		20600	181811.6279	5410.91	11602.5641	219425.10	8951600.00	40.80
2		16375	252109.3023	2596.36	12179.48718	283260.15	11720500.00	41.38
2		22250	238632.5581	5847.272727	15961.53846	282691.37	11561300.00	40.90
								<b>37.25</b>

