AFSSAAE

Advances in Food Science, Sustainable Agriculture and Agroindustrial Engineering 2024, 7(1), 67-77
ISSN 2622-5921

ORIGINAL RESEARCH Open Access

The influence of seed separation techniques and drying temperature in a dehumidified drying machine for tomato seed production

Mochamad Bagus Hermanto*, Bambang Susilo, Mustofa Lutfi, Retno Damayanti, Yanti and Irshafiyah

Department of Biosystems Engineering, Faculty of Agricultural Technology, Universitas Brawijaya, Malang, Indonesia

KEYWORDS

Drying
Germination
Relative humidity
Separation
Temperature
Tomato seeds
Vigor

ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) is a horticultural plant with high economic value, consumed as fresh fruit or a processed product. However, this plant still requires serious handling, especially in tomato seeds. The seeds are coated with quite slimy flesh and need to be separated using a suitable method so that the flesh layer can be cleaned optimally. Tomato seeds have a high water content, causing the seeds to easily damaged and quickly decrease their viability. Therefore, it is necessary to dry the seeds properly to lower the water content while maintaining the seed's quality. This research aimed to calculate the time needed to reduce the water content of tomato seeds in a dehumidified drying machine, analyze the germination percentage of tomato seeds resulting from dehumidified drying using various separation techniques, and measure the effect of separation techniques. The temperature of dehumidified drying affects the germination and vigor of tomato seeds. The experiment was carried out using a two factorial Completely Randomized Design (CRD) method, namely separation technique (i.e., left for 24 hours, using 2% HCl, and using 10% Na_2CO_3) and temperature in a dehumidified drying machine (i.e., 30, 40, 50, and 60 °C). The highest germination percentage and vigor index were produced in the treatment with 2% HCl for 2 hours with a drying temperature of 40°C. The separation technique and drying temperature influenced the germination percentage and vigor index, but the interaction between separation techniques had no effect.

Introduction

Tomato (*Lycopersicon esculentum Mill.*) is a plant native to Central and South America from the Solanaceae family. Based on their uses, tomatoes are categorized as vegetable,s but as fruit based on their plant parts (Gould, 1992). It has flat, slightly hairy seeds and is coated with pulp or slimy flesh. Therefore, tomato seeds should be separated using the correct method to clean the flesh layer optimally. Seed separation techniques can be done manually, using chemicals, or fermentation. The manual separation technique is carried out by crushing the tomatoes, placing them in a nylon bag and squeezing them by hand. Then, the seeds are removed and filtered using water if they still have pulp (Ravel et al., 2016). Seed separation techniques by fermentation are generally carried out for 3 days at 20-25°C or 24 hours in warmer areas (George, 1999). Besides, the separated tomato seeds generally have a high water content ranging from 16% to 20% (Kolo and Tefa, 2016). Therefore, the seeds are easily damaged and quickly reduced their viability. Drying the seeds properly is crucial to lowering the water content and maintaining the seeds' quality.

Drying is a method that involves heating a material, causing the transfer of water vapor to the material's surface and thus reducing its water content. This method is often used for food preservation to increase shelf life and improve product quality (Onwude et al., 2016). Drying food can be done in two ways: naturally and artificially. One of the artificial drying types that is considered efficient is dehumidified drying. Dehumidified drying uses heat as an energy source to move the water content in the material. Drying with a dehumidification system can reduce drying time and maintain the quality of the dried material (Sabareesh et al., 2021). The working principle of a dehumidifier is that environmental air will enter the evaporator, which has a temperature cooler than room temperature. When the temperature is

*Corresponding author
E-mail address: mbhermanto@ub.ac.id

Received on 30 November 2023, Revised on 27 December 2023, Accepted on 18 March 2024

below the dew point, the condensation of water vapor in the air occurs (Susilo et al., 2020).

This research aimed to calculate the time needed to reduce the water content of tomato seeds in a dehumidified drying machine, analyze the germination percentage of tomato seeds resulting from dehumidified drying using various separation techniques, and measure the effect of separation techniques.

Research and methods

Materials

Tomatoes (*Solanum lycopersicum*) with Gustavo cultivar were used as samples. The ripe tomatoes with 85-90% red skin were obtained from the Karangploso market. For each treatment, 1 kg of tomatoes with an average diameter of 5 ±1 cm was required. Other materials used were 2% HCl solution, 10% Na_2CO_3 solution, straw paper, manure, and soil.

Tomato seed processing

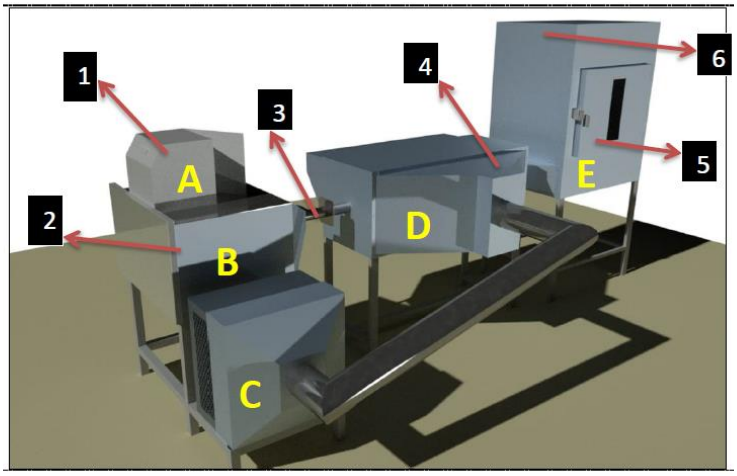
The prepared tomato fruit samples were sliced crosswise, separating the flesh from the skin. Then, the flesh and seeds were placed in three containers for different separation methods: pulling out the tomato seed and flesh from the fruit and leaving for 24 hours, using HCl 2 % for 2 hours, and using Na_2CO_3 10 % for 24 hours. After that, the tomato seeds were washed 4-5 times and dried using a dehumidified drying machine.

Tomato seed drying process

A dehumidified drying machine is a drying machine that can dry seeds at low temperatures and relative humidity (RH) without causing damage to the seeds and perform faster drying time (Susilo et al., 2020). The dehumidified drying machine consists of several parts, namely the control box, dehumidifier room, AC (Air Conditioner), Heat Recovery Unit, and drying room (with 3 trays capacity of 50 cm x 50 cm for each tray), as shown in Figure 1. This machine works on the principle that air is passed into the evaporator so that the temperature becomes cooler than room temperature, and a condensation process occurs. When the dehumidifier temperature reaches the dew point temperature, the water vapor condenses and drips down, then the dry air flows to the heat recovery unit for further use in the heating room (Susilo et al., 2022). Temperature and RH measurements on this drying machine use the DHT22 sensor. This sensor is placed at 6 points, as seen in Figure 1. Samples of tomato seeds to be dried were 4.5 g per treatment. Tomato seeds was dried until the water content reaches 5-6% with four temperature variations (i.e., 30, 40, 50, and 60 °C).

Seed viability testing

The germination test can be carried out using the top-of-paper method Magureanu et al. (2018), the on-paper roll method, and the sand method (Oliveria et al., 2014). The germination of tomato seeds was tested using the top-of-paper method. The prepared straw paper is placed in a thin-wall container and wet until damp. Then, the tomato seeds are placed on paper and spaced apart. Seed germination was observed on the 10th day after planting.



A: Control box, **B:** Dehumidifier unit, **C:** Condensor, **D:** Heat recovery unit, **E:** Drying chamber
Position of DHT22 sensor: 1: Ambient, **2:** Dehumidifier unit, **3:** Air outlet after dehumidifier chamber, **4:** Air outlet after heat recovery unit, **5:** Drying chamber, **6:** Air outlet after drying chamber

Figure 1. The design of the dehumidifier drying machine (Susilo et al., 2022).

Seed vigor testing

The vigor test on tomato seeds was carried out in a greenhouse using planting media in the form of soil and goat manure as fertilizer. The ratio of soil and manure used is 5:1, which required 1000 g of soil and 200 g of goat manure in one tray. After the tomato seeds were placed on the planting medium, broken bricks with 1-2 cm thick were added to test their growth strength in a sub-optimal environment. The seed vigor parameters used were the vigor percentage and seed growth rate. The sprout's vigor was observed on the 10^{th} day after planting, while the seed growth rate was from the 2^{nd} day after planting until the 10^{th} day.

Energy efficiency of the dehumidified drying machine

Energy efficiency was obtained by comparing outgoing energy with incoming energy. The formula used to calculate the energy efficiency of the dehumidified drying machines can be seen in the equation below.

$$\eta = \frac{Q_o}{Q_i}\ x\ 100\% \qquad (1)$$

η = Energy efficiency (%)
Q_o = Output energy (kcal)
Q_i = Input energy (kcal)

The input energy is obtained from the total energy required by dehumidified drying machine components such as dehumidifiers, fans, heaters, blowers, and electronic circuits. The formula used to calculate the energy input of the dehumidified drying machines can be seen in the equation below.

$$Q_{electronics} = P_{electronics} \times t \qquad (2)$$

$P_{electronics}$= Total electronic power (kW)
T = Drying time (hours)

The output energy is obtained from the total drying energy of tomato seeds, which consists of energy to heat the tomato seeds, energy to heat the water content in tomato seeds, and energy to evaporate the water content in the tomato seeds. The formula used to calculate the energy output of the dehumidified drying machines can be seen in the equation below.

a. Heating energy for tomato seeds

$$Q_{tomato} = m_{tomato} \times Cp_{tomato} \times \Delta T \qquad (3)$$

m_{tomato} = Mass of tomato seeds (g)
Cp_{tomato} = Specific heat of tomato (J/kg°C)
ΔT =Difference between drying room temperature and ambient temperature (°C)

b. Heating energy for the water content in tomato seeds

$$Q_h = W_i \times Cp_{water} \times \Delta T \qquad (4)$$

W_i = Mass of initial water (g)
Cp_{water} = Specific heat of water (J/kg°C)
ΔT = Difference between drying room temperature and ambient temperature (°C)

c. Evaporation energy for the water content in tomato seeds

$$Q_e = W_r \times hfg \qquad (5)$$

W_r = Mass of evaporated water (g)
hfg = Enthalpy of vaporization (kJ/kg)

Analysis method

The data from the calculation of the germination percentage, vigor percentage, and seed growth rate was tested using the Analysis of Variance (ANOVA) method with a significance value of 5%. Further tests were then carried out using the Least Significance Difference (LSD) if any differences were observed. If the significance value was less than 0.01 ($p<0.01$), then a further test is carried out using LSD at a 1% level. If the significance value was between 0.05 and 0.01 ($0.05>p\geq0.01$) then a further test is carried out using LSD at a 5% level.

Results and Discussion

Temperature and relative humidity

Data on temperature and relative humidity were obtained from sensor readings at six predetermined points. The distribution of temperature and relative humidity during the drying process at temperatures of 30, 40, 50, and 60°C, respectively, as shown in Figure 2.

The distribution of temperature and RH in the dehumidifier room shows a stable condition, which was controlled below the dew point temperature. The controlled condition kept the RH in the dehumidifier room close to 100%. In the dehumidifier room, the intake air was cooled below the dew point temperature to produce dry air by removing contained water through condensation (Djaeni et al., 2021). The dry air from the dehumidifier room is then heated through a heater in the heat recovery unit to increase the temperature. The distribution of RH in the drying room positively correlated with the drying temperature set point. The higher the drying temperature, the greater the RH difference between the drying room and the environment, with the following decrease in RH of 30 °C at 14.25%, 40 °C at 52.62%, 50 °C at 58.53%, and 60 °C at 75.37%, respectively.

The findings confirmed that the higher the temperature setting, the higher the air humidity difference between the drying room and the environment. At a drying temperature of 30 °C, the slowest drying time was 165 minutes with an average RH of 52.5%. The fastest drying time of 45 minutes was at 60°C, with an average RH of 20%. This shows that increasing the drying temperature decreases the drying air RH, increases the water evaporation in the drying chamber, and speeds up the drying process.

Moisture content

Observations were made at dehumidified drying and oven drying at 40 °C as a control. The average initial water content in the tomato seeds left for 24 hours was 30.54%, with 2% HCl for 2 hours was 34.66%, with 10% Na_2CO_3 for 24 hours was 33.71% and in the control treatment was 69.8%. The tomato seeds were dried until the final water content reached 5-6% for all treatments. Figure 3 shows the trends in water content for all treatments.

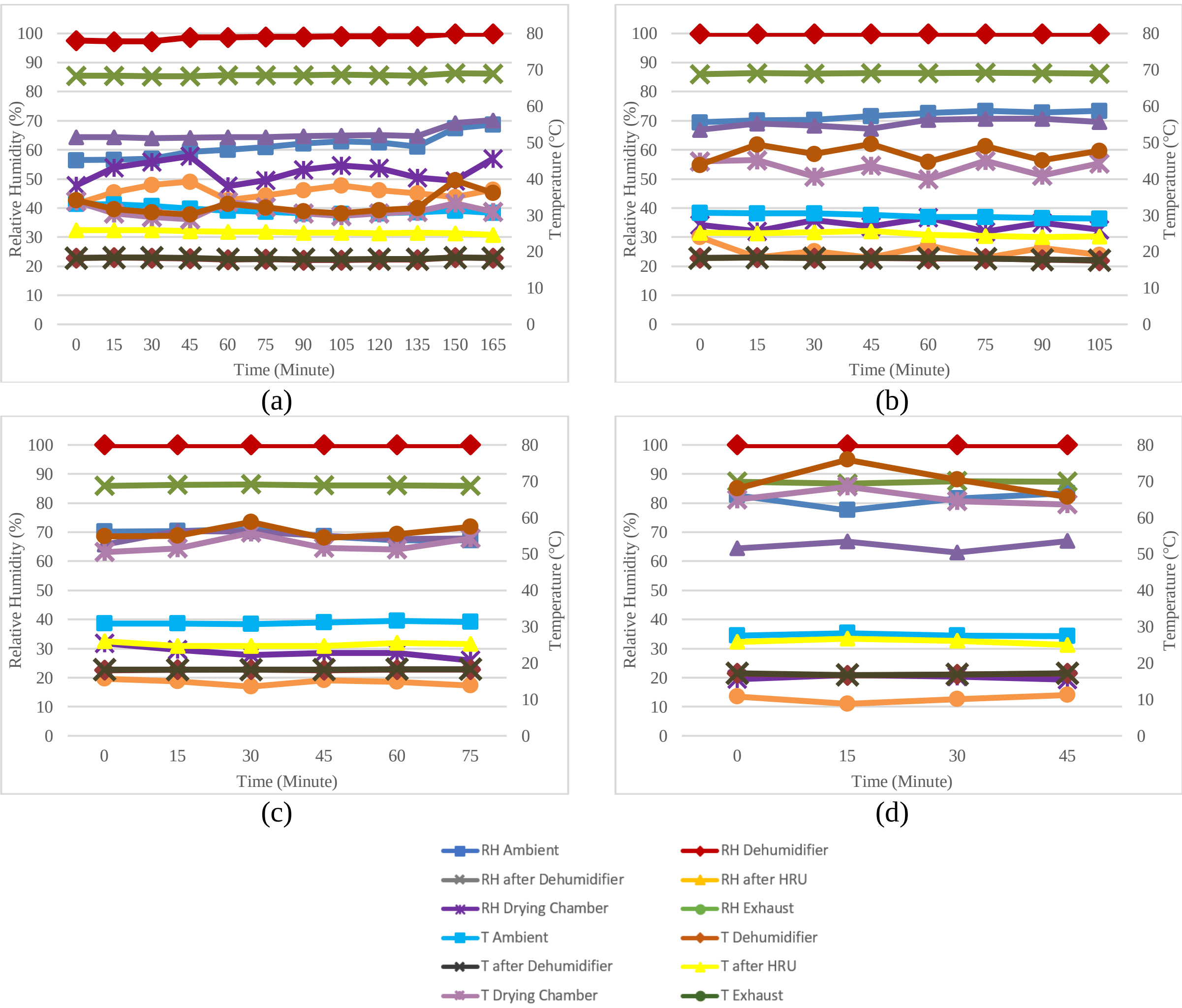
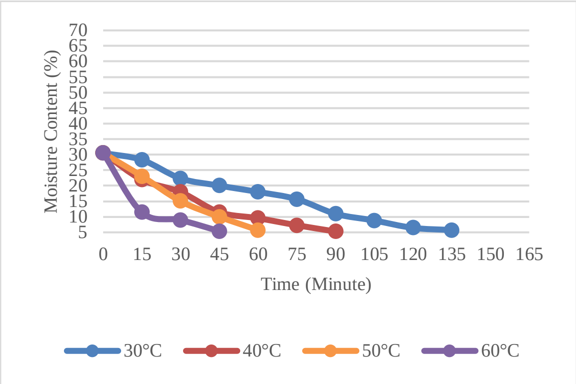
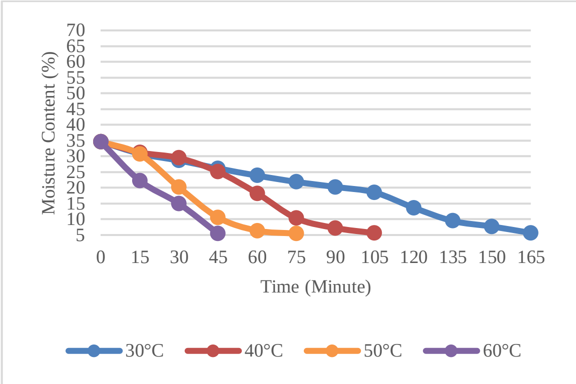


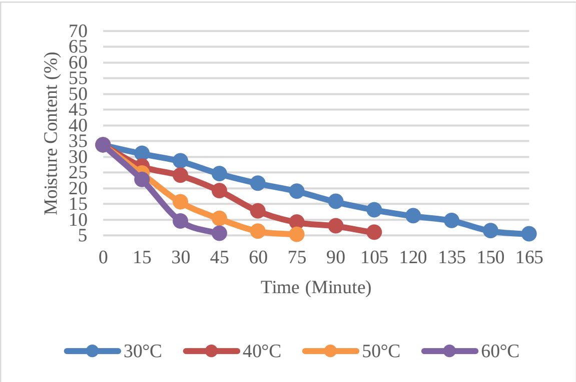
Figure 2. Temperature and relative humidity distribution during drying at 30°C (a), 40°C(b), 50°C(c) and 60°C(d)



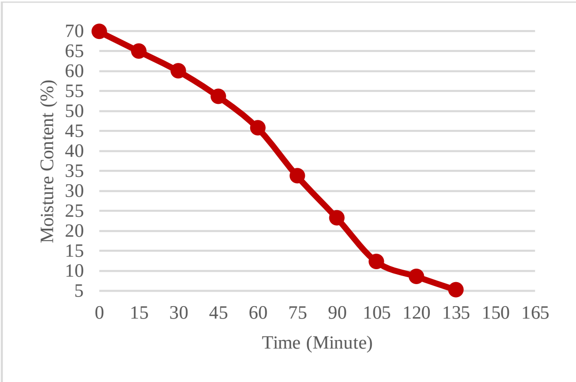
(a)



(b)



(c)



(d)

Figure 3. Decrease in moisture content in the (a) tomato seeds that left in water for 24 hours, (b) using 2% HCl for 2 hours, (c) using 10% Na_2CO_3 for 24 hours, and (d) oven drying at 40 °C (control)

Based on Figure 3, the decrease in water content in both tomato seeds subjected to separation and control treatment shows an inverse relationship to drying time. The drying process in the treatment using 2% HCl and 10% Na_2CO_3 lasted longer than the tomato seeds that were left for 24 hours. This was because of the difference in the initial water content of the materials. The results indicate that the initial moisture content of the material and drying temperature can influence drying time. The higher the initial moisture content of the material, the longer the drying time. On the other hand, the higher the temperature in the drying room, the faster the drying time. In the control treatment, the time needed to reduce the water content to 5-6% was 135 minutes. Compared with drying tomato seeds previously separated at the same temperature, oven drying took longer due to differences in initial water content and RH in the drying room. Drying with a dehumidified machine could reduce RH by up to 75%, while oven drying was only 50% (Susilo et al., 2020).

Based on data of decreasing water content, the highest drying rate for tomato seeds subjected to separation treatment was at a drying temperature of 60 °C, with values of 0.559%/minute (leaving for 24 hours), 0.648%/minute (using 2% HCl), and 0.627%/minute (using10% Na_2CO_3). The control treatment with oven drying at 40 °C had a drying rate of 0.478%/minute. Treating tomato seeds in different chemical solutions affects changes in water content and drying rate. Using 2% HCl gave a higher initial water content than 10% Na_2CO_3 with the same drying time to reach a final water content of 5-6%. This could be due to the lower boiling point of HCl than the Na_2CO_3 solution. When the temperature reaches the boiling point, the liquid molecules receive enough energy to escape from the material's surface into the air, causing evaporation (Zhao et al., 2020). Figure 4 shows the drying rate of tomato seeds. The differences in drying rates can be caused by several factors, such as temperature, airflow velocity, type of product, initial moisture content of the material, and total mass of the product (Lingayat et al., 2020). The decrease in water content of tomato seeds at the beginning of the drying process occurs more quickly and slows down as the drying time increases. This is because the free water content contained in the material is still relatively high, so the water is easily evaporated. In contrast, the water content at the end of the drying process begins to be difficult to evaporate due to the bonding of the water content in the material (Ummah et al., 2016).

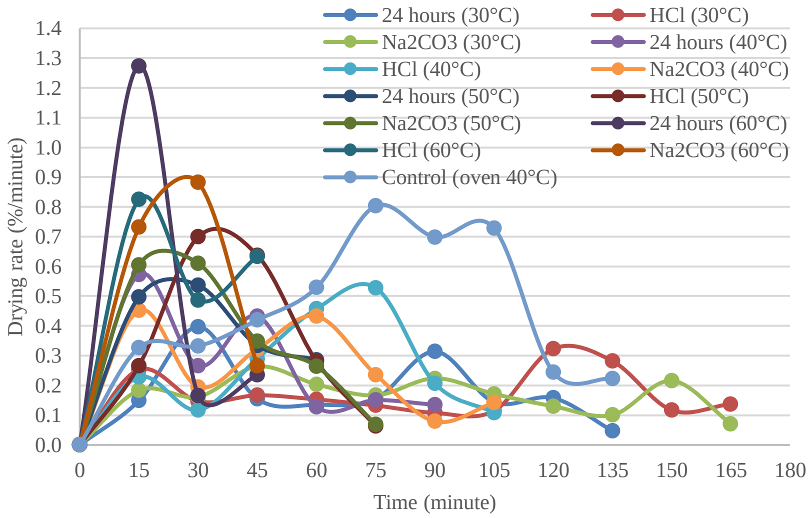


Figure 4. Drying rate in the drying process of tomato seeds

Energy efficiency of the dehumidified drying machine

Energy efficiency is defined as the ratio of output energy to input energy (Dai et al., 2013). The total electrical power of the dehumidified drying machine is 1.99 kW. Each treatment requires a different time to reach a water content of 5-6%, so energy consumption in each treatment is different. Energy consumption in dehumidified drying machines can be seen in Table 1.

Electrical energy consumption in drying at 30, 40, and 50 °C of the tomato seeds left for 24 hours was smaller compared to the other two treatments, possibly due to the faster drying time. When drying at 60 °C, the energy consumption was the same between the three treatments. The results demonstrate that increasing drying time parallels to an increase in the energy required (Asgar et al., 2022).

Based on the efficiency calculations in Table 2, the energy efficiency is very small (< 0.1%). The highest energy efficiency for each treatment was found at a drying temperature of 60 °C, which can speed up the drying time, thus lowering the energy consumption. This study indicates that the energy efficiency of the dehumidified drying machine was not optimal because of the small size and mass of fresh and dried tomato seeds. The dehumidified drying machine has a large capacity and power in one drying process. This finding confirmed that the mass of incoming material can influence energy efficiency l. If the energy produced by a machine is large but the materials supplied are small, it causes an imbalance in the energy use and decreases energy efficiency (Putra, 2018).

Germination test

Viability is an important parameter for measuring the quality of a seed. Viability can be measured by testing germination and the results are shown in Table 3.

Table 1. Energy consumption in dehumidified drying machines

Seed Separation Technique	Drying Temperature (ºC)	Electrical Energy Consumption (kcal)
Leaving the tomato seeds and flesh for 24 hours	30	3846.412
	40	2564.275
	50	1709.517
	60	1282.137
Treatment of 2% HCl for 2 hours	30	4701.17
	40	2991.654
	50	2136.896
	60	1282.137
Treatment of 10% Na_2CO_3 for 24 hours	30	4701.17
	40	2991.654
	50	2136.896
	60	1282.137

Table 2. Energy efficiency in dehumidified drying machines

Seed Separation Technique	Drying Temperature (ºC)	Energy Efficiency (%)
Leaving the tomato seeds and flesh for 24 hours	30	0.0179
	40	0.0295
	50	0.0458
	60	0.0677
Treatment of 2% HCl for 2 hours	30	0.0171
	40	0.0290
	50	0.0424
	60	0.0768
Treatment of 10% Na_2CO_3 for 24 hours	30	0.0167
	40	0.0280
	50	0.0413
	60	0.0747

Table 3. Germination of tomato seeds

Seed Separation Technique	Drying Temperature (ºC)	Germination Percentage (%)
Leaving the tomato seeds and flesh for 24 hours	30	68.9
	40	68.9
	50	84.4
	60	67.8
Treatment of 2% HCl for 2 hours	30	86.7
	40	91.1
	50	77.8
	60	73.3
Treatment of 10% Na_2CO_3 for 24 hours	30	82.2
	40	83.3
	50	84.4
	60	64.4
Oven drying at 40°C		55.6

Table 4. Further test results of germination parameters of separation techniques and drying temperature

Seed Separation Technique	Germination Percentage (%)
Leaving the tomato seeds and flesh for 24 hours	72.50^{a}
Treatment of 10% Na_2CO_3 for 24 hours	78.61^{ab}
Treatment of 2% HCl for 2 hours	82.22^{b}
Drying Temperature (°C)	**Germination Percentage (%)**
60	68.52^{a}
30	79.26^{b}
40	81.11^{b}
50	82.22^{b}

Note: Different notation letters indicate a significant difference at the significance level (P<0.01).

Based on the test results, the highest percentage of germination was in the treatment with 2% HCl for 2 hours and drying in a dehumidified drying machine at 40 °C, with a value of 91.1%. The lowest percentage of germination was in the control treatment (oven drying at 40 °C), with a value of 55.6%. The ANOVA test results show no significant effect on the interaction between drying temperature and tomato seed separation technique on the germination percentage of tomato seeds. However, the drying temperature and separation technique separately significantly affected the germination percentage.

Table 4 shows that the separation treatment by leaving the tomato seeds for 24 hours and using 2% HCl for 2 hours significantly affects the germination percentage. The best treatment was found from treatment using 2% HCl for 2 hours. Furthermore, Table 4 indicates that all drying temperatures have a significant effect on the germination percentage, where the best drying temperature was at 50 °C.

These findings confirmed that the separation technique and drying temperature significantly affect tomato seeds' germination. Separating tomato seeds using 2% HCl was the best treatment because it can remove the pulp covering the seeds better than the other counterparts. The acid content in HCl has been proven could clean inhibitors attached to seeds quickly and increase the permeability of the seed coat; thus, the seeds can germinate more easily (Raval et al., 2016).

Vigor test

Vigor testing was conducted in sub-optimum environmental conditions for 10 days of germination. The vigor index was obtained by counting normal sprouts that grow with the criteria of having primary roots, secondary seminal roots, perfect hypocotyl growth, perfect plumula with green leaves, and perfect epicotyl growth with normal buds (Siregar et al., 2020). The results of tomato seed vigor testing can be seen in Table 5.

The highest vigor percentage was in the treatment with 2% HCl for 2 hours using a dehumidified drying machine at 40 °C, with a value of 91.1%. The lowest germination percentage was in the control treatment, with a value of 51.1%. The ANOVA test results identified that the interaction between drying temperature and tomato seed separation technique did not significantly affect the vigor percentage. However, separately drying temperature and separation techniques significantly affected the vigor percentage.

Table 6 shows that the separation treatment by leaving the tomato seeds for 24 hours and using 2% HCl for 2 hours significantly affected the vigor percentage. In contrast, the treatment using 10% Na_2CO_3 for 24 hours did not significantly affect the vigor percentage. Table 6 also demonstrates that the drying temperature at 40, 50, and 60°C had a significant effect on the vigor percentage, but not at 30 °C.

These findings concluded that the tomato seed separation technique with the 2% HCl was superior to other techniques. Furthermore, the best drying temperature for tomato seeds was 40 °C. This aligns with a previous study that the optimal temperature for drying seeds to minimize physical and chemical damage is between 40.5 and 43.3 °C (Devi and Mani, 2019).

Table 5. Vigor of tomato seed

Seed Separation Technique	**Drying Temperature (°C)**	**Vigor (%)**
Leaving the tomato seeds and flesh for 24 hours	30	57.8
	40	61.1
	50	72.2
	60	55.6
Treatment of 2% HCl for 2 hours	30	86.7
	40	91.1
	50	67.8
	60	66.7
Treatment of 10% Na_2CO_3 for 24 hours	30	68.9
	40	82.2
	50	83.3
	60	60.0
Oven drying at 40°C		51.1

Table 6. Further test results of vigor parameters of separation techniques and drying temperature

Seed Separation Technique	**Vigor (%)**
Leaving the tomato seeds and flesh for 24 hours	61.67^{a}
Treatment of 10% Na_2CO_3 for 24 hours	73.61^{ab}
Treatment of 2% HCl for 2 hours	78.05^{b}
Drying Temperature (°C)	**Vigor (%)**
60	60.74^{a}
30	71.11^{ab}
50	74.44^{b}
40	78.15^{b}

Note: Different notation letters indicate a significant difference at the significance level (P<0.05).

Table 7. The growth rate of tomato seed

Seed Separation Technique	Drying Temperature (°C)	Seed Growth Rate (%/etmal)
Leaving the tomato seeds and flesh for 24 hours	30	10.536
	40	12.067
	50	10.334
	60	7.685
Treatment of 2% HCl for 2 hours	30	13.624
	40	12.446
	50	10.074
	60	9.854
Treatment of 10% Na_2CO_3 for 24 hours	30	9.363
	40	11.513
	50	11.140
	60	8.016
Oven drying at 40°C		7.855

Table 8. Further test results of seed growth rate parameters of separation techniques and drying temperature

Seed Separation Technique	Seed Growth Rate (%/etmal)
Leaving the tomato seeds and flesh for 24 hours	8.808[a]
Treatment of 10% Na_2CO_3 for 24 hours	10.008[ab]
Treatment of 2% HCl for 2 hours	11.173[b]
Drying Temperature (°C)	**Seed Growth Rate (%/etmal)**
60	8.370[a]
50	10.090[b]
30	10.480[b]
40	11.046[b]

Note: Different notation letters indicate a significant difference at the significance level ($P<0.01$).

Seed growth rate

Seed growth speed is one of the parameters of seed vigor. Seeds that grow faster indicate that the seeds have high vigor (Ebone et al., 2020). Table 7 shows that the highest value of seed growth speed was in the treatment with 2% HCl for 2 hours using a dehumidified drying machine at 30°C, giving a value of 13.624%/etmal. The lowest seed growth speed was in the tomato seeds left for 24 hours with drying at 60 °C, with a value of 7.685%/etmal. The ANOVA test results indicated that the interaction between drying temperature and tomato seed separation technique had no significant effect on the growth speed of tomato seeds. However, the separation technique and drying temperature each had a very significant effect on the seed growth rate.

Table 8 shows a similar trend that the separation treatment by leaving the tomato seeds for 24 hours and using 2% HCl for 2 hours significantly affected the seed growth rate. However, the separation technique using 10% Na_2CO_3 for 24 hours did not significantly affect the seed growth rate. The separation technique using 2% HCl for 2 hours was the best treatment due to completely removing the pulp covering the seeds. Table 8 indicates that the drying temperature treatment at 30, 40, 50, and 60 °C had a significant effect on the seed growth rate, as indicated by different letter notations. Similar to the previous findings, drying at 40 °C optimal performance than other treatments.

Conclusions

In separation seed treatment of leaving tomato seeds for 24 hours with drying temperatures of 30, 40, 50, and 60°C required a drying time of 135, 90, 60, and 45 minutes to reach a 5-6% water content. The drying time needed in the treatment using 2% HCl for 2 hours and 10% Na_2CO_3 for 24 hours with drying temperatures of 30, 40, 50, and 60 °C were 165, 105, 75, and 45 minutes. The highest germination and vigor percentage were found in the treatment of 2% HCl for 2 hours with a drying temperature of 40°C, with a value of 91.1%. The control (oven drying at 40 °C) had the lowest percentage, with values of 55.6% and 51.1%. This finding confirmed that a 2% HCl solution could clean seed flesh optimally compared to other treatments. Moreover, a drying at 40°C was the optimal temperature for tomato seeds. The interaction between the separation technique and drying temperature had no significant effects on germination, vigor, and seed growth rate. Meanwhile, the separation technique and drying temperature each significantly affected the germination percentage, vigor percentage, and seed growth rate.

Declarations

Conflict of interests The authors declare no competing interests.

References

Asgar, A., Musaddad, D., Rahayu, S. T., and Levianny, P. S. (2022) 'Effect of temperature and drying time on chemical, physical and organoleptic characteristics of dry winged beans', *IOP Conferences Series: Earth and Enviromental Science*, pp. 1 – 12

Dai, M., Tang, D., Giret, A., Salido, M. A., and Li. W. D. (2013) 'Energy-efficient scheduling for a flexible flow shop using an improved genetic-simulated annealing algorithm', *Robotic and Computer-Integrated Manufacturing*, 29(5), pp. 418 – 429

Devi, T. B., and Mani, I. (2019) 'Effect of temperature on drying kinetics of vegetable seeds thingujam', *Journal of Agricultural Engineering*, 56(2), pp. 100 – 110

Djaeni, M., A'Yuni, D. Q., Alhanif, M., Hii, C. L., and Kumoro, A. C. (2021) 'Air dehumidification with advance adsorptive materials for food drying: A critical assessment for future prospective', *Drying Technology*, 39(11), pp. 1648 – 1666

Ebone, L. A., Caverzan, A., Tagliari, A., Chiomento, J. L. T., Silveira, D. C., amd Chavarria, G. (2020) 'Soybean seed vigor: Uniformity and growth as key factors to improve yield', Agronomy, 10(4), pp. 1-15

George, R. (1999) *Vegetable Seed Production*. NewYork: CAB International

Gould, W. A. (1992) *Tomato Production, Processing and Technology Third Edition* . Sawston: Woodhead Publishing

Kolo, E., and Tefa, A. (2016) 'Pengaruh kondisi simpan terhadap viabilitas dan vigor benih tomat *(Lycopersicum esculentum Mill)* (Effect of storage conditions on the viability and vigor of tomato seeds (Lycopersicum esculentum Mill)', *Jurnal Pertanian Konservasi Lahan Kering*, 1(3), pp. 112-115 [In Indonesian]

Lingayat, A. B., Chandramohan, V. P., Raju, V. R. K., and Meda, V. (2020) 'A review on indirect type solar dryers for agricultural crops–dryer setup, its performance, energy storage and important highlights', *Applied Energy*, 258, pp. 1-22

Magureanu, M., Sirbu, R., Dobrin, D., and Gidea, M. (2018) 'Stimulation of the germination and early growth of tomato seeds by non-thermal plasma', *Plasma Chemistry and Plasma Processing*, 38, pp. 989 – 1001

Oliveria, G. L., Dias, D. C. F. D. S., Hilst, P. C., Silva, L. J. D., and Dias, L. A. D. S. (2014) 'Standard germination test in physic nut *(Jatropha curcas L.)* seeds', *Journal of Seed Science*, 36(3), pp. 336 – 343

Onwude, D. I., Hashim, N., Janius, R. B., Nawi, N. M., and Abdan, K. (2016) 'Modeling the thin-layer drying of fruit and vegetables: A Review', *Comprehensive Reviews in Food Science and Food Safety*, 15(3), pp. 599-618

Putra, R. P. (2018) Uji Performansi Mesin Pengering RH (Relative Humidity) Rendah Terhadap Kadar Air Cabai Merah Besar (*Capsicum annuum L.)* (Low RH (Relative Humidity) Drying Machine Performance Test on Water Content of Large Red Chilies (*Capsicum annuum L*.). Undergraduate Thesis. Universitas Brawijaya, Malang. [In Indonesian]

Raval, A., Sasidharan, N., and Rao, K. (2016) 'Effect of seed extraction procedures on seed quality parameters in tomato', *Advances in Life Sciences*, 5(20), pp. 9020-9024

Sabareesh, V., Milan, K. J., Muraleedharan, C., and Rohinikumar, B. (2021) 'Improved solar drying performance by ultrasonic desiccant dehumidification in indirect forced convection solar drying of ginger with phase change material', *Renewable Energy*, 169, pp. 1280 – 1293

Siregar, L. A. M., Lubis, K., Putrie, L. A. P., and Adelia, L. (2020) 'Screening of varieties of cayenne pepper (*Capsicum frutescens L.*) on salinity resistance through in vitro culture technique', *In Proceedings of the International Conference of Science, Technology, Engineering, Environmental and Ramification Researches (ICOSTEERR 2018)*, pp. 54 – 60

Susilo, B., Hermanto, MB., and Damayanti, R. (2022) 'Performance of dehumidifier drying machine for soybean seeds drying', *IOP Conferences Series : Earth and Enviromental Science*, pp. 1 -7

Susilo, B., Hermanto, MB., Mujahidin, A., Djoyowasito, G., and Damayanti, R. (2020) 'Performance of drying machine with air dehumidifying process for sweet corn seed (*Zea mays saccharata*)', *IOP Conferences Series: Earth and Enviromental Science*, pp. 1 – 6

Ummah, N., Purwanto, Y. A., and Suryani, A. (2016) 'Penentuan konstanta laju pengeringan bawang merah *(Allium ascalonicum L.)* iris menggunakan tunnel dehydrator (Determination of the drying rate constant of sliced shallots (*Allium* *ascalonicum L*.) using a tunnel dehydrator)', *Warta Industri Pertanian*, 33(02), pp. 49 – 56 [In Indonesian]

Zhao, F., Guo, Y., Zhou, X., Shi, W., and Yu, G. (2020) 'Materials for solar-powered water evaporation', *Review Article*, 5(5), pp. 388 – 401