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# Effects of spacing on yield and head characteristics of cabbage (*Brassica oleracea* var. *capitata* L.) in two agro-ecologies of Ethiopia

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**Cabbage (*Brassica oleracea* var. *capitata*) is one of the major vegetable crops grown in Ethiopia. In the 2018 rainy season, 31,400 tonnes of head cabbage was produced. Despite its importance, the productivity of cabbage in Ethiopia remains very low (6 t/ha) as compared to world (28.8 t/ha) and East Africa (16 t/ha). Low plant population was one of the major causes of low yield and big size heads, which consumers and vendors do not prefer. Therefore, an experiment that comprised two cabbage varieties and seven spacings was undertaken at two agro-ecologies during the 2018 and 2019 rainy seasons. Results of the experiment showed that the highest yields of Copenhagen market (99.69 t ha$^{-1}$) and Landini F1 (96.9 t ha$^{-1}$) were obtained at spacings of 40 cm × 20 cm and 40 cm × 30 cm as compared to the control (59.78 t ha$^{-1}$), which is a 66.7 and 74.2% increase over the control. Therefore, the spacings of 40 cm × 20 cm and 40 cm × 30 cm were recommended for Copenhagen market and Landini F1 varieties, respectively. At the same time, Kulumsa was a suitable site for growing both varieties of head cabbage.**

**Key words:** Cabbage, *Brassica oleracea* var. *capitata*, plant population, spacing.

## INTRODUCTION

Cabbage (*Brassica oleracea* var. *capitata* L.) is one of the most popular vegetable crops grown worldwide. The total annual world production of cabbages and other brassicas in 2018 was about 69 million metric tonnes (FAO, 2021). while East African countries produced 14.8 million tonnes of cabbage on about 92.5 thousand ha of land during the same year. Cabbage is also among the widely grown vegetable crops in Ethiopia. In the rainy season (June-August) of 2018, 31,400 tonnes of cabbage was produced on 5,200 hectare of land involving 439 thousand households (CSA, 2018). The productivity of cabbage in Ethiopia is very low (6 t/ha) compared to global (28.8 t/ha) and East Africa (16 t/ha) output.

Cabbage is known worldwide as a source of vitamin C,

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minerals and dietary fiber. In Ethiopia, cabbage is usually grown in the mid and high altitude areas of the country both for household consumption and as a source of income. Moreover, the portion of cabbage is exported to neighboring countries of Djibouti and Somalia. In 2018, the country exported 1,575 tonnes of cabbage and lettuce to these countries and earned about 300 thousand USD (8.27 million Birr) (ERCA, 2018).

Although cabbage is source of food, income, foreign currency and employment, its production and productivity has been gripped by several problems. Lack of adapted varieties for the different agro-ecologies of the country, unimproved insect and disease management systems and agronomic practices are among the major constraints that resulted in low productivity and quality in cabbage. Cabbage head size depends on choice cultivar as well as on cultural practices such as plant population and rate of fertilization (Semuli, 2005; Kołota and Chohura, 2015). Moreover, growth and development of cabbage head vary within and between production fields, forcing growers to undertake multiple harvests. Production practices such as uniform spacing of plants contribute in reducing such variability in plant growth, development and ultimately head size of cabbage. Marketable yields, for a once-over-harvest, were higher from fields with uniform cabbage head size (Stoffellal and Fleming, 1990). Plant population plays a significant role in the final crop yield and quality under any given condition (Adeboye, 1996; Alofe et al., 1996; Mutungamiri et al., 2001). Carlson et al. (2003) also reported that evenly spaced stands of plants resulted in optimum plant population, that gave greater yields than unevenly spaced stands. Blanket recommendation of 60 cm between rows and 40 cm between plants has been used for all varieties and across production areas in Ethiopia. However, the use of the above spacing led to the production of big size heads often with low production per unit area. The big sized heads, however, were not preferred among retailers and consumers as they were not amenable to existing retailing system. Therefore, the need for optimum plant population (spacing) that results in high yield and desirable head size has become unequivocal. The objective of the current study is thus to determine the optimum spacing suitable for two com-monly grown varieties across two major agro-ecologies: the high-altitude and mid-altitude areas of the country.

## MATERIALS AND METHODS

The experiment comprised two varieties and six spacing treatments. The varieties were an open pollinated variety with medium head size Copenhagen Market (MoA, 2018) and a hybrid variety with large head size Landini F1 (Hazera Seeds, Israel). Both varieties were grown widely in the mid and highlands of the country. Six spacing treatments (40 cm × 20 cm, 40 cm × 30 cm, 40 cm × 40 cm, 50 cm × 20 cm, 50 cm × 30 cm, 50 cm × 40 cm) were compared with the commonly used spacing (60 cm × 40 cm) as a control. The corresponding plant populations per ha were 125000, 83333, 62500, 100000, 66666, 50000 and 41666, respectively. The experiment was undertaken at Debre Zeit and Kulumsa Agricultural Research centers. Debre Zeit has an altitude of 1860 m.a.s.l., annual min. and max. temperatures of 8.9 and 28.3°C and Alfisol soils; while Kulumsa has an altitude of 2200 m.a.s.l., annual minimum and maximum temperatures of 10 and 22°C and Luvisol soils (EIAR, 2021).

Seeds of both varieties were sown on raised seed beds and the seedlings were grown for a month until they attained 3 to 4 leaves. The seedlings were transplanted on 22/08/2018 and 18/07/2019 at Debre Zeit, and on 18/09/2018 and 14/08/2019 at Kulumsa. The treatments received uniform application of 242 kg of NPS at transplanting and 130 kg urea in two splits, half at transplanting and the remaining half 30 days after transplanting. Karate (1 l/ha) and Dimetiote (Roger, 1 l/ha) were sprayed against cabbage aphids and flea beetles as deemed necessary (Mengistu and Seid, 1990).

Factorial combinations of variety and spacing treatments were laid out in randomized complete block design (RCBD), with three replications on a plot size of 4 $m^2$ per treatment. Five random samples of matured heads were harvested from the central plants to record data such as: diameter, height and weight of heads, and number and weight of non-wrapper leaves. Total yield per plot was recorded as the weight of matured heads in the central rows of each plot, excluding boarder plants. Yield per ha was calculated. All the other data were analyzed using Satistix 8 statistical package (Analytical Software, 2008) and those which showed significant differences among the treatments were separated using Tukey's test at 0.05 level of probability.

## RESULTS AND DISCUSSION

### Head yield and head characteristics

The four way interaction among location, year, variety and spacing and the three way interactions except for location, year and variety were not significant for the studied parameters. The significant interaction among location, year and variety was only in head height and weight (Table 1). However, the difference was not significant in head diameter, number and weight of non-wrapper leaves. Both Copenhagen Market and Landini F1 produced better heads at Kulumsa as compared to those produced at Debre Zeit. Coppenhagen Market and Landini F1 grown at Kulumsa produced 29.5, 24.0, 12.2 and 22.8% better head height and 90.7, 82.3, 64.9 and 89.9% better head weight than those grown at Debre Zeit during the respective growth periods of 2018 and 2019 (Table 1). The better yield at Kulumsa indicated that the plants at Kulumsa were effective in head formation rather than spending their photosynthates on forming non-wrapper leaves. This is due to the fact that cool agro-ecologies are more suitable for head formation of cabbage than warmer agro-ecologies. Dixon (2007) indicated that Brassicas need vernalizing temperature of below 10°C to initiate heads. The results further confirmed that Copenhagen Market was more suitable in highland areas like Kulumsa than in the midlands such as Debre Zeit.

The interaction between variety and spacing was not significant for the studied parameters, except for yield (Table 2). The highest yield (99.69 t $ha^{-1}$) of Copenhagen

**Table 1.** Interaction effects of location, year and variety (combined over spacing) on yield and yield components of head cabbage.

| Season | Year | Variety | Head diameter (cm) | Head height (cm) | Head weight (kg) | Yield (t/ha) | Non-wrapper leaves plant$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Number | Weight (kg) |
| Kulumsa | 2018 | Copenhagen Market | 14.89 | 18.63$^{a}$* | 2.06$^{a}$ | 87.99 | 12.7 | 0.70 |
| | | Landini F1 | 14.70 | 17.75$^{a}$ | 1.75$^{ab}$ | 74.17 | 11.41 | 0.77 |
| | 2019 | Copenhagen Market | 12.99 | 14.95$^{c}$ | 1.55$^{b}$ | 87.34 | 7.66 | 0.39 |
| | | Landini F1 | 12.75 | 16.38$^{b}$ | 1.50$^{b}$ | 79.45 | 8.42 | 0.34 |
| Debre Zeit | 2018 | Copenhagen Market | 14.50 | 14.39$^{cd}$ | 1.08$^{c}$ | 83.34 | 15.14 | 0.67 |
| | | Landini F1 | 13.30. | 14.32$^{cd}$ | 0.96$^{c}$ | 68.16 | 13.78 | 0.72 |
| | 2019 | Copenhagen Market | 13.30 | 13.33$^{d}$ | 0.94$^{c}$ | 66.88 | 12.04 | 0.48 |
| | | Landini F1 | 12.18 | 13.33$^{d}$ | 0.79$^{c}$ | 68.83 | 11.38 | 0.47 |
| **S.E.** | | | 0.39 | 0.44 | 0.1 | 8.08 | 0.44 | 0.05 |
| **Critical value** | | | ns | 1.36 | 0.32 | ns | ns | ns |
| **CV (%)** | | | 9.12 | 9.27 | 24.90 | 25.69 | 12.40 | 29.03 |

Market was obtained when plants were spaced 40 cm between rows and 20 cm between plants as compared to the control (59.78 t ha$^{-1}$). It has a 66.7% increase over the control. However, there were no significant differences among the other spacings of Copenhagen Market. Unlike Copenhagen Market, Landini F1 produced the highest yield (96.9 t ha$^{-1}$) when planted at 40 cm between rows and 30 cm between plants. It has an increase of 74.2% compared to the control, which produced only 55.63 t ha$^{-1}$. However, no significant differences were observed in yield among the plants of Landini F1 planted at 40 cm × 30 cm, 40 cm × 20 cm and 50 cm × 20 cm spacings. The interactions among variety, year and location, and between variety and spacing were not significant for number and weight of non-wrapper leaves (Tables 1 and 2).

The means of variety main factor also indicated that Copenhagen Market produced higher yield (81.39 t/ha) than Landini F1 (72.65 t/ha) irrespective of location, year and spacing treatments. The two varieties, however, did not differ in mean diameter, height, and weight of heads.

Significant differences in yield and yield components were also observed in both locations depending on production year, irrespective of variety and spacing (Table 3). Cabbage produced at Kulumsa in 2018 and 2019 had 7.0 and 22.9% better head yields than those grown at Debre Zeit during the respective years. Moreover, the highest head diameter, head height, head weight, and number of non-wrapper leaves were observed in the cabbage grown at Kulumsa in 2018. The head weight of cabbage grown at Kulumsa was significantly bigger than those grown at Debre Zeit in both years; cabbage grown at Kulumsa had the highest (1.9 kg) head weight compared to those grown at Debre Zeit (0.86 kg) in 2019. Those grown at Debre Zeit during the same year had similar head diameter and number of non-wrapper leaves as those grown at Kulumsa though they had smaller head height and weight. No significant difference in head height and weight of non-wrapper leaves were observed among the treatments. Likewise, Stoffellal and Felming (1990) reported a yield difference of 30% between two consecutive years in cabbage (cv. Bravo). Kleinhenz and Wszelaki (2003) also reported significant differences in marketable yield, head weight, head diameter, and head density between years and seasons.

The interaction between location and spacing was not significant for diameter and height of head. Significant interactions, however, were observed in head weight and yield (Table 4). At Debre Zeit, the biggest head of 1.65 kg was observed at 50 cm × 40 cm which was 41.0 and 39.8% bigger than those grown at 40 cm × 20 cm and 40 cm × 30 cm, respectively; but it had similar head weight as the control. Cabbage head yield obtained at 40 cm × 30 cm spacing was about double compared to those grown under the control treatment though it did not differ from those grown at 40 cm × 20 cm and 50 cm × 20 cm, which produced 81.5 and 57.4% better yield than the control. Likewise, cabbage grown at Kulumsa had bigger heads when grown at 50 cm × 40 cm; they are 47.5% bigger than those grown at 40 cm × 20 cm in the same location. But it did not differ from those grown at similar spacing at Debre Zeit. Nonetheless, the head yield obtained at 40 cm × 20 cm spacing was significantly better (34.8%) than the control.

Generally, the main effects of location indicated that there was better head height (16.9 cm), head weight (1.7 kg), and yield (82.24 t/ha) at Kulumsa compared to Debre Zeit which had 13.8 cm, and 0.94 kg, 71.8 t/ha of the respective parameters.

**Table 2.** Interaction of variety and spacing on yield and some yield components of cabbage (combined over location and year).

| Variety | Treatment (Spacing; $cm^2$) | Head diameter (cm) | Head height (cm) | Head weight (kg) | Total yield (t/ha) | Non-wrapper leaves $plant^{-1}$ | |
|---|---|---|---|---|---|---|---|
| | | | | | | Number | Weight (kg) |
| Copenhagen | 40 × 20 | 12.79 | 15.13 | 1.17 | 99.69$^{a}$* | 10.87 | 0.45 |
| | 40 × 30 | 13.02 | 14.88 | 1.18 | 82.18$^{a-d}$ | 11.19 | 0.50 |
| | 40 × 40 | 14.52 | 15.95 | 1.50 | 81.58$^{a-d}$ | 11.35 | 0.55 |
| | 50 × 20 | 12.93 | 14.71 | 1.22 | 81.14$^{a-d}$ | 11.63 | 0.56 |
| | 50 × 30 | 13.71 | 15.61 | 1.37 | 86.10$^{abc}$ | 11.73 | 0.54 |
| | 50 × 40 | 14.15 | 15.69 | 1.65 | 79.23$^{a-d}$ | 12.65 | 0.72 |
| | 60 × 40 | 13.99 | 15.29 | 1.49 | 59.78$^{cd}$ | 13.46 | 0.59 |
| Landini F1 | 40 × 20 | 13.27 | 14.87 | 1.01 | 77.99$^{a-d}$ | 10.02 | 0.45 |
| | 40 × 30 | 14.11 | 15.49 | 1.29 | 96.91$^{ab}$ | 10.35 | 0.54 |
| | 40 × 40 | 13.95 | 15.52 | 1.39 | 65.77$^{cd}$ | 11.26 | 0.61 |
| | 50 × 20 | 13.85 | 15.67 | 1.18 | 79.16$^{a-d}$ | 11.17 | 0.51 |
| | 50 × 30 | 13.42 | 15.04 | 1.36 | 69.26$^{bcd}$ | 11.52 | 0.66 |
| | 50 × 40 | 14.48 | 16.18 | 1.49 | 63.85$^{cd}$ | 11.71 | 0.62 |
| | 60 × 40 | 14.02 | 15.34 | 1.28 | 55.63$^{d}$ | 12.32 | 0.65 |
| **S.E.** | | 0.51 | 0.58 | 0.14 | 8.08 | 0.58 | 0.07 |
| **Critical value** | | ns | ns | ns | 27.68 | ns | ns |
| **CV (%)** | | 9.12 | 9.29 | 24.90 | 25.69 | 12.40 | 29.03 |

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns- Non-significant difference.

**Table 3.** Interaction of location and year on yield and some yield components of cabbage (combined over spacing and variety).

| Location | Year | Head diameter (cm) | Head height (cm) | Head weight (kg) | Yield (t/ha) | Non-wrapper leaves $plant^{-1}$ | |
|---|---|---|---|---|---|---|---|
| | | | | | | Number | Weight (kg) |
| Kulumsa | 2018 | 14.69$^{a}$* | 18.19 | 1.90$^{a}$ | 81.08$^{a}$ | 12.05$^{b}$ | 0.74$^{a}$ |
| | 2019 | 12.87$^{b}$ | 15.66 | 1.53$^{b}$ | 83.40$^{a}$ | 8.34$^{c}$ | 0.36$^{c}$ |
| Debre Zeit | 2018 | 14.62$^{a}$ | 14.35 | 1.02$^{c}$ | 75.75$^{ab}$ | 14.36$^{a}$ | 0.70$^{a}$ |
| | 2019 | 12.74$^{b}$ | 13.33 | 0.86$^{c}$ | 67.85$^{b}$ | 11.71$^{b}$ | 0.47$^{b}$ |
| **S.E.** | | 0.27 | 0.31 | 0.07 | 4.32 | 0.31 | 0.04 |
| **Critical value** | | 0.71 | ns | 0.19 | 11.26 | 0.81 | 0.09 |
| **CV (%)** | | 9.12 | 9.27 | 24.90 | 25.69 | 12.40 | 29.03 |

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns- Non-significant difference.

Significant differences were observed among the spacing treatments in yield, head diameter, head weight, and number and weight of non-wrapper leaves but not in head height (Table 5). There was an increase in yield, head diameter, head weight, and number and weight of non-wrapper leaves, with an increase in the space a plant occupies. Growing cabbages, irrespective of variety, in a 40 cm inter 30 cm intra-row spacing produced 55.2% better yield than the control and 25.2% better yield than the 50 cm inter- and 40 cm intra-row spacings. However, there was no significant difference between the other (40 cm × 20 cm, 40 cm × 30 cm, 40 cm × 40 cm, 50 cm × 20 cm, and 50 cm × 30 cm) spacings. Likewise, an increase of 27.5% in head weight, 24.4% in number of non-wrapper leaves, 42.8% in weight of non-wrapper leaves were observed as the spacing was reduced from commonly used 60 cm × 40 cm to 40 cm × 20 cm without significantly reducing the head diameter (7.4%).

**Table 4.** Interaction of location and spacing on yield and some yield components of cabbage (combined over variety and year).

| Location | Treatment (Spacing; $cm^2$) | Head diameter (cm) | Head height (cm) | Head weight (kg) | Total Yield (t/ha) | Non-wrapper leaves $plant^{-1}$ | |
|---|---|---|---|---|---|---|---|
| | | | | | | Number | Weight (kg) |
| Debre Zeit | 40 × 20 | 12.79 | 13.80 | $1.17^{bc}$* | $85.93^{abc}$ | 11.83 | 0.46 |
| | 40 × 30 | 13.02 | 14.03 | $1.18^{bc}$ | $97.33^{a}$ | 12.12 | 0.51 |
| | 40 × 40 | 14.52 | 14.17 | $1.50^{ab}$ | $65.66^{bcd}$ | 12.78 | 0.59 |
| | 50 × 20 | 12.93 | 13.74 | $1.23^{abc}$ | $74.56^{a-d}$ | 12.75 | 0.56 |
| | 50 × 30 | 13.71 | 13.42 | $1.37^{abc}$ | $68.93^{bcd}$ | 13.30 | 0.65 |
| | 50 × 40 | 14.15 | 14.29 | $1.65^{a}$ | $62.67^{cd}$ | 13.93 | 0.74 |
| | 60 × 40 | 13.99 | 13.44 | $1.49^{ab}$ | $47.35^{d}$ | 14.53 | 0.59 |
| Kulumsa | 40 × 20 | 13.27 | 16.21 | $1.01^{c}$ | $91.75^{ab}$ | 9.09 | 0.45 |
| | 40 × 30 | 14.11 | 16.33 | $1.30^{abc}$ | $81.77^{abc}$ | 9.42 | 0.52 |
| | 40 × 40 | 13.95 | 17.31 | $1.39^{abc}$ | $81.69^{abc}$ | 9.83 | 0.56 |
| | 50 × 20 | 13.85 | 16.64 | $1.18^{bc}$ | $85.74^{abc}$ | 10.34 | 0.51 |
| | 50 × 30 | 13.42 | 17.24 | $1.36^{abc}$ | $86.43^{abc}$ | 9.95 | 0.55 |
| | 50 × 40 | 14.48 | 17.57 | $1.49^{ab}$ | $80.22^{abc}$ | 10.43 | 0.60 |
| | 60 × 40 | 14.02 | 17.18 | $1.29^{abc}$ | $68.06^{bcd}$ | 11.25 | 0.65 |
| **S.E.** | | 0.51 | 0.58 | 0.14 | 8.08 | 0.58 | 0.07 |
| **Critical value** | | ns | ns | 0.46 | 27.68 | ns | ns |
| **CV (%)** | | 9.12 | 9.29 | 24.90 | 25.69 | 12.40 | 29.03 |

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns-Non-significant difference.

**Table 5.** Main effects of spacing (combined over location, year and variety) on yield and yield components of head cabbage.

| Treatment | Plant population $ha^{-1}$ | Head diameter (cm) | Head height (cm) | Head weight (kg) | Yield (t/ha) | Non-wrapper leaves $plant^{-1}$ | |
|---|---|---|---|---|---|---|---|
| | | | | | | Number | Weight (kg) |
| 40 cm × 20 cm | 125000 | $13.03^{b}$* | 15.00 | $1.09^{c}$ | $88.84^{a}$ | $10.46^{c}$ | $0.45^{c}$ |
| 40 cm × 30 cm | 83333 | $13.57^{ab}$ | 15.18 | $1.23^{bc}$ | $89.55^{a}$ | $10.77^{bc}$ | $0.52^{bc}$ |
| 40 cm × 40 cm | 62500 | $14.23^{a}$ | 15.74 | $1.45^{ab}$ | $73.68^{abc}$ | $11.30^{bc}$ | $0.58^{abc}$ |
| 50 cm × 20 cm | 100000 | $13.39^{ab}$ | 14.19 | $1.21^{bc}$ | $80.15^{ab}$ | $11.55^{bc}$ | $0.53^{bc}$ |
| 50 cm × 30 cm | 66666 | $13.56^{ab}$ | 15.33 | $1.36^{abc}$ | $77.68^{ab}$ | $11.63^{bc}$ | $0.60^{ab}$ |
| 50 cm × 40 cm | 50000 | $14.32^{a}$ | 15.93 | $1.57^{a}$ | $71.54^{bc}$ | $12.18^{ab}$ | $0.67^{a}$ |
| 60 cm × 40 cm | 41666 | $14.00^{ab}$ | 15.31 | $1.39^{ab}$ | $57.7^{c}$ | $12.89^{a}$ | $0.62^{ab}$ |
| **S.E.** | | 0.36 | 0.41 | 0.1 | 5.71 | 0.41 | 0.05 |
| **Critical value** | | 1.08 | ns | 0.29 | 17.15 | 1.24 | 0.14 |
| **CV (%)** | | 9.12 | 9.27 | 24.9 | 25.69 | 12.40 | 29.03 |

*Means followed by the same letter are not significantly different at 5% level of probability by Tukey's test at 0.05 level of probability. ns-Non-significant difference.

However, the cabbage plants grown in different spacings had the same head height. The results agree with that of Stoffellal and Fleming (1990) who reported that cabbage head weight increased quadratically as within row spacing increased. Uniformity among plants and head weights also increased with increase in within row spacing due to improved availability of light, nutrient and water. Barrett et al. (2015) also indicated that wider within row spacing reduced interplant competition in high-density cabbage production, thereby maximizing the proportion of marketable heads (yield). Similarly, Haque et al. (2015) recorded the highest number of loose leaves(19), weight (849 g), diameter (19 cm), and thickness (12 cm) of cabbage head in wide (50 cm × 50 cm) spacing than in

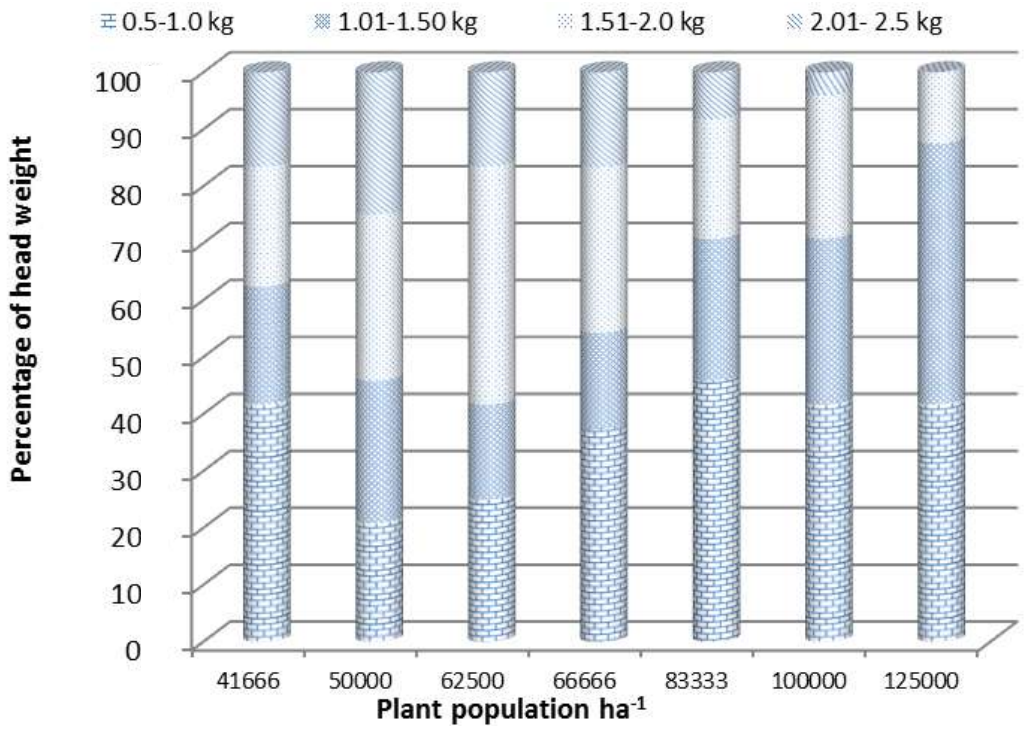


**Figure 1.** Cumulative percentage of different head size categories recorded in cabbage grown at different plant populations.

narrow (50 cm × 30 cm) spacing which resulted in 14, 617 g, 16 cm, and 11 cm of the respective parameters. They attributed the better growth of plants in the wider spacing to availability of sufficient light and nutrients which led to optimum vegetative growth. The highest head weight per plant (1.65 kg) and marketable yield (66.07 t $ha^{-1}$) were recorded in the wide spacing than the narrow spacing which resulted in smaller head size (1.32 kg) and yield (52.7 kg).

### *Head weight uniformity*

The different spacing treatments also showed differences in size and uniformity of heads. Results in Figure 1 showed that there was a linear increase in the proportion of smaller (0.5-1.0 kg) and medium (1.01-1.5 kg) sized heads with higher population density. More than 87% of cabbage heads produced in the densest plant population (125000 $ha^{-1}$) weighed between 0.5 and 1.5 kg, while the remaining 12.5% were those which weighed between 1.51 and 2.0 kg, with no heads in the largest size category. On the other hand, there was an increase in the proportion of large sized heads (1.51 - 2.0 kg and over 2 kg) with wider spacing or reduced plant population. The highest proportions (58.3, 54.2, 45.8 and 37.5%) of medium and large heads (1.51 and 2.5 kg) were produced with 62500, 50000, 66666 and 41,666 plants $ha^{-1}$, respectively. Kołota and Chohura (2015) recorded 75.2% marketable yield (≥ 1.5 kg heads size) when cabbage was grown at 44000 plants $ha^{-1}$; whereas only 32.2% was marketable at the densest population of 74000 plants $ha^{-1}$.

### Correlation among parameters

Correlation analysis among the parameters showed that head diameter (r = 0.26), head height (r = 0.38) and head weight (r = 31) had positive and highly significant correlation with yield (Table 6). On the other hand, number and weight of non-wrapper leaves had non-significant correlation with yield.

Significant positive correlations were also observed among diameter, height and weight of heads. Moreover, the parameters were positively and significantly correlated with weight of non-wrapper leaves but they had non-significant correlations with the number of non-wrapper leaves. This indicates that plants with vigorous leaves produced big size heads.

## Conclusion

Cabbage (*B. oleracea* var. *capitata*) is one of the major vegetable crops grown in Ethiopia. 31.4 thousand tonnes

**Table 6.** Correlation among yield and yield component parameters of cabbage.

| Parameter | Head diameter | Head height | Head weight | yield | No. non-wrapper leaves plant$^{-1}$ | Weight non-wrapper leaves plant$^{-1}$ |
|---|---|---|---|---|---|---|
| Head diameter | | 0.55** | 0.52** | 0.26** | 0.20* | 0.53** |
| Head height | 0.55** | | 0.82** | 0.38** | -0.08 | 0.44** |
| Head weight | 0.52** | 0.82** | | 0.31** | -0.06 | 0.56** |
| Yield | 0.26** | 0.38** | 0.31** | | -0.17 | 0.04 |
| No. non-wrapper leaves | 0.20* | -0.08 | -0.06 | -0.17 | | 0.42** |
| Weight non-wrapper leaves | 0.53** | 0.44** | 0.56** | 0.04 | 0.42** | |

n for diameter, height and weight of head and yield = 168 and for no. and weight of non-wrapper leaves = 126.

of cabbage was produced in 2018 rainy season. Despite its importance, the productivity of cabbage in Ethiopia (6 t/ha) is about five and three folds lower than that of the world (28.8 t/ha) and East Africa (16 t/ha). Low plant population was one of the causes of low productivity. Moreover, big size heads resulting from lower populations were not usually preferred by consumers and retailers. The current study was thus conducted to improve the yield and size of cabbage. The study was undertaken using two cabbage varieties commonly grown in Ethiopia and seven spacing treatments, including the control 60 cm × 40 cm, at Debre Zeit and Kulumsa during 2018 and 2019. The experiment was laid out in RCBD with three replications. Results of the experiment showed that Copenhagen Market produced the best yield (99.69 t ha$^{-1}$) at 40 and 20 cm between rows and plants, respectively; whereas Landini F1 produced the highest yield (96.9 t ha$^{-1}$) at 40 cm inter and 30 cm intra-rows. The control, on the other hand, produced only 59.78 t. Better yields of both varieties were observed at Kulumsa than at Debre Zeit. Therefore, the 40 cm × 20 cm and 40 cm × 30 cm spacings are recommended for Copenhagen and Landini F1, respectively. Kulumsa is the most preferred location for growing both cabbage varieties. As the study was conducted at two locations and two varieties, it is thus, recommended to undertake further studies involving cabbage varieties with different head sizes and at different agro-ecologies.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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