Growth, carrageenan content and gel strength of *Kappaphycus alvarezii* seaweed from different sources at different depths

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Abstract. The quality of *Kappaphycus alvarezii* (Doty) seaweed is strongly influenced by several factors such as water depth and also the habitat characteristics of the seaweed (seed source). In this study, we examined the effects of differences in water depth (0-25 cm, 25-50 cm, and 50-75 cm) and sources of seaweed seeds (Towua, Latambaga, and Samaturu villages) on the daily growth rate (DGR), carrageenan yield, and gel strength of *K. alvarezii*. The results showed that the highest DGR for *K. alvarezii* was obtained for seeds from Latambaga (3.71%±0.03% day^{-1}), followed by Samaturu (3.60±0.04% day^{-1}) and Towua (2.82±0.11% day^{-1}), at an optimal depth of 0-25 cm. The highest carrageenan yields were obtained from Towua (24.17±2.28%), followed by Samaturu (23.48±0.54%) and Latambaga (22.02±11.46%), at an optimal depth of 25-50 cm. The highest gel strength was obtained from Towua (323.57±48.30 g cm^{-2}), followed by Latambaga (299.88±50.96 g cm^{-2}), and Samaturu (181.13±26.43 g cm^{-2}), at an optimal depth of 0-25 cm. There were significant differences ($p<0.05$) between treatments with different depths and sources of seaweed seeds in DGR and gel strength values. The carrageenan yield was not significantly different among treatments. The best quality seeds of *K. alvarezii* originate from the waters of Towua village, which can become a centre for seaweed cultivation, especially in Kolaka Regency.
Key Words: carrageenan yield, daily growth rate, gel strength, seed source, water depth.

Introduction. In Indonesia, *Kappaphycus alvarezii* seaweed has long been cultivated by seaweed farmers. Seaweed is a superior commodity with a high economic value because it contains industrial raw material compounds, especially agar and carrageenan. Seaweed growth is highly dependent on oceanographic factors such as salinity, physical and chemical properties, and the dynamics of ocean movement. These help to carry nutrients from the surrounding environment by diffusion and osmosis through the thallus wall in the seaweed, which in turn affects its chemical composition.

Studies reveal that the growth of seaweed and production of carrageenan in seaweed depend on the variety, location, weather, time and method of cultivation (Radiarta et al 2016). In addition to obtaining optimal benefits from seaweed cultivation at various locations, the Indonesian government has also announced in 2015 that starting from 2018, a policy to gradually reduce exports of seaweed raw materials and from 2020 to ban exports would be enforced (Zuraya & Candra 2015). Following this government policy, it is recommended to export processed materials, such as gelatine and carrageenan flour.

Considering these developments, good sources of kappa-carrageenan, namely *K. alvarezii* and *Eucheuma cottonii,* were considered for cultivation in the coastal areas of Indonesia. Different planting depths had a significant effect ($p<0.01$) on the relative growth and daily growth rate (DGR) of seaweed. The relative growth of seaweed was almost three times higher at a planting depth of 25 cm than at 75 cm (Susilowati et al 2014). Hence, the main determining factor for the success or failure of seaweed cultivation depends on the selection of a suitable location, especially when the seaweed grows naturally (FAO 2017).

The aim of this study was to evaluate the weight and DGR, carrageenan yield and gel strength of seaweed grown at different depths and from seeds sourced at different locations. The data and information obtained from this study are expected to act as a reference for optimal and beneficial seaweed cultivation for seaweed farmers to increase their income. This initial trial will lead to further research related to seaweed cultivation in Towua village. Seaweed cultivation in this coastal area is highly dependent on the varied and changing weather. The constantly changing climate often affects the productivity of seaweeds.

Material and Method

Description of the study location. This research was conducted from May to July 2017 in the waters of Towua village, Kolaka Regency, southeast of Sulawesi Province, Indonesia (Figure 1). The cultivated seaweed seeds were taken from three water sources: from the villages of Towua, Latambaga, and Samaturu. The waters of Latambaga and Samaturu villages are at a distance of approximately 40 and 80 km, respectively, from Towua. Analyses of carrageenan content and gel strength of Kappaphycus seaweed in this study was carried out at the Nutrition Laboratory, Department of Aquaculture, Pangkep State Agricultural Polytechnic, Indonesia.

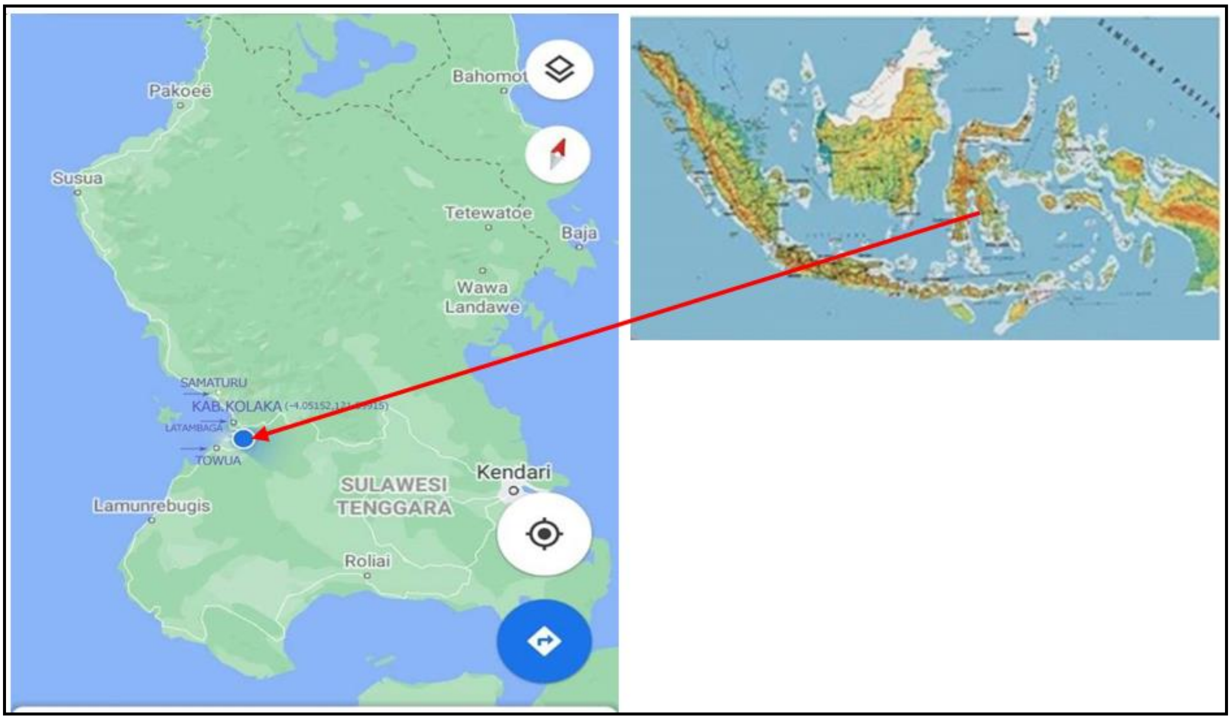

Figure 1. Location of study in Towua, Latambaga, and Samaturu villages.

Seaweed cultivation. Cultivation of *K. alvarezii* was carried out in the waters of Towua village using the longline method (Figure 2) at various depths (0-25 cm; 25-50 cm; 50-75 cm) and seeds sourced from three areas, namely the waters of Towua, Latambaga, and Samaturu villages. The initial weight of the seedlings in each treatment was 100 g.

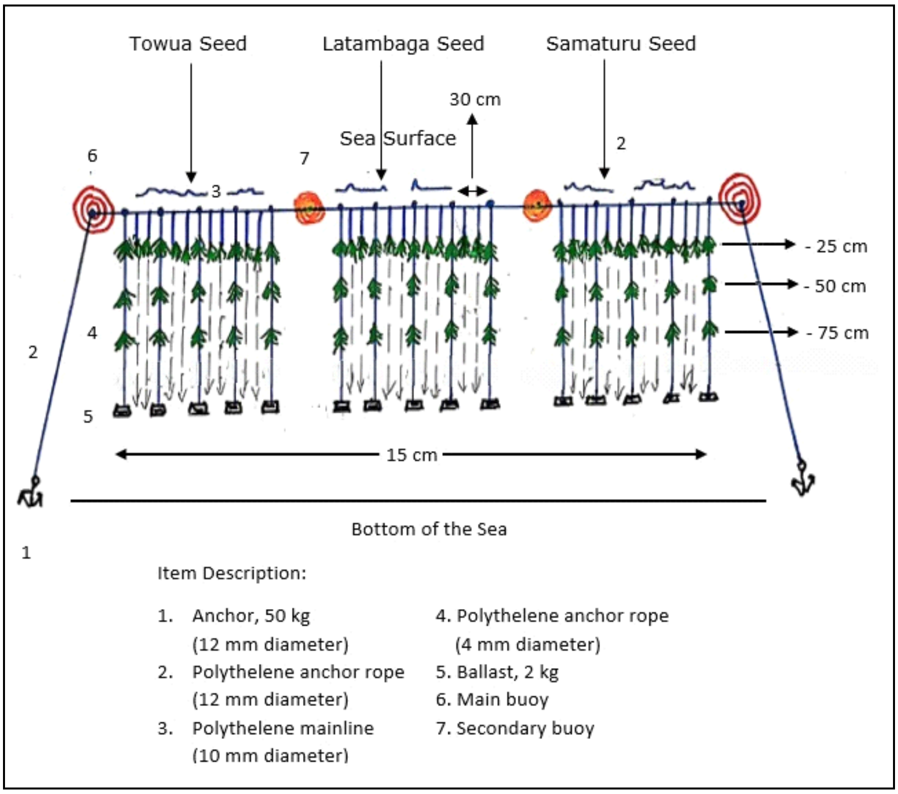

Figure 2. The vertical long line method.

Determination of the average weight and DGR of seaweed. The average weight is obtained from three randomly selected fresh seaweeds at the end of cultivation of 45 days (Yong et al 2013).

DGR (g day^{-1}) = $[(W_t – W_o)^{1/t} – 1)] \times 100$

Where: W_o - the initial fresh weight; W_t - the final fresh weight of seaweed 1 day after cultivation.

Determination of carrageenan yield. The seaweed prepared for carrageenan extraction was air-dried (average daily temperature of 32-33^{0}C) for approximately 2 days, then dried in an oven at 50^{0}C for 48 hours. The carrageenan content was analyzed by seaweed extraction using the Suryaningrum (1992) method, namely: dried seaweed was soaked in 1% chlorine solution for 1 hour and then washed until the pH was neutral. The extraction took place in 0.5% KOH at a temperature of 90-95^{o}C for 3 hours with a ratio of 1:40. The extract was filtered and dehydrated with IPA (2:1) then dried and milled. The resulting carrageenan was then analyzed for its yield. Carrageenan yield (%) was determined according to the formula of Munoz et al (2004):

Yield = $(W^c/W^{ds}) \times 100$

Where: W^c - weight of carrageenan extract (g); W^{ds} - weight of dry algae (g) used for extraction. The mean of three repeated measurements (mean ± standard deviation) was considered.

Determination of gel strength. A 0.3 g sample of carrageenan was dissolved in hot aquadest (1.5%:w/v). Potassium chloride (0.2%) was added. The solution was heated to boiling point (85°C) and stirred to dissolve the carrageenan extract and salt. A 100 mL volume of distilled water was added to obtain the initial concentration of carrageenan (1.5%:w/v). The solution was transferred to three 20 mL beakers. The gels were stored overnight at 4°C. The gel was allowed to stand for 20 min at 25°C before measurement. The gel strength (g cm^{-2}) at 25°C was measured on carrageenan discs (3 cm high, 7 cm in diameter) using a texture analyser with a probe area of 1 cm^2 operating at a rate of decline of 1.0 mm s^{-1}. The analysis was performed in three replicates. Gel strength was measured in terms of the maximum penetration pressure required to break the gel (Munoz et al 2004).

Water quality analysis. The environmental parameters measured were salinity, with a hand refractometer, temperature, with a digital thermometer, pH with a pH meter, dissolved oxygen with a DO meter, current with a drift float. The chemical parameters such as ammonia, nitrite, and nitrate were measured using spectrophotometry. Water quality parameters were measured *in situ* every week.

Seaweed monitoring and observation. The DGR of *K. alvarezii* was determined using a factorial design with three treatment depths and three replications for 45 days. Carrageenan content and gel strength data were recorded on the last day of the study for each treatment depth.

Statistical analysis. The homogeneity of the research data was tested using Levene's test and the effects of water depth and seed source on the average weight, DGR, carrageenan content and gel strength of seaweed were analysed using the two-way Manova test (multivariate analysis of variance) and Tukey's post hoc test was performed using SPSS version 22.

Results and Discussion. The different locations of cultivation in the waters of Towua village showed significantly different results for DGR, carrageenan yield, and gel strength. In general, the water quality at the experimental location was in accordance with the water quality standards prescribed for seaweed cultivation (Table 1).

Table 1

The water quality at 45 days of the experiment

No	*Parameters*	*Results*	*Optimal range*	*Unit*
1	Salinity	27-30	27-34 (b)	ppt
2	Temperature	30-32	20-33 (a)	°C
3	Current	15-16	20-30 (c)	cm sec^{-1}
4	pH	7-8	69 (c)	-
5	Oxygen	4.2-4.5	3-5 (c)	mg L^{-1}
6	Ammonia	0.11-0.12	0-01	mg L^{-1}
7	Nitrite (NO_2)	0.004-0.005	0.001-0.008 (a)	mg L^{-1}
8	Nitrate (NO_3)	0.97-1.95	0.93-3.5 (a)	mg L^{-1}

Note: a - BSN (2011); b - WWF-Indonesia (2014); c - Atmadja et al (1996).

Average weight and daily growth. The average weight of seaweed seeds at the depths of 0-25 cm, 25-50 cm and 50-75 cm was as follows: for Towua seeds, 259±21.83 g, 197.50±27.65 g and 145.75±5.38 g, respectively; for Latambaga seeds, 430.75±33.36 g, 352.25±5.50 g and 307.75±25.40 g, respectively; for Samaturu seeds, 385.25±12.47 g, 325.50±13.03 g and 283.75±16.50 g, respectively.

The daily growth of seaweed at the depths of 0-25 cm, 25-50 cm and 50-75 cm was as follows: for Towua seaweed, 2.82±0.11% day^{-1}, 2.36±0.14% day^{-1} and 2.04±0.03% day^{-1}; for Latambaga seeds, 3.71±0.03% day^{-1}, 3.40±0.01% day^{-1} and 3.24±0.04% day^{-1}; and for Samaturu seeds, 3.60±0.04% day^{-1}, 3.3±0.05% day^{-1} and 3.08±0.06% day^{-1}, respectively. The highest mean weight and DGR were obtained from Latambaga, followed by Samaturu and Towua seedlings (Figures 3 and 4). The DGR value (g day^{-1}) showed the same pattern for all seaweed at each depth. The average growth and DGR values decreased with increase in depth. Seaweed colour during harvest is presented in Figure 5.

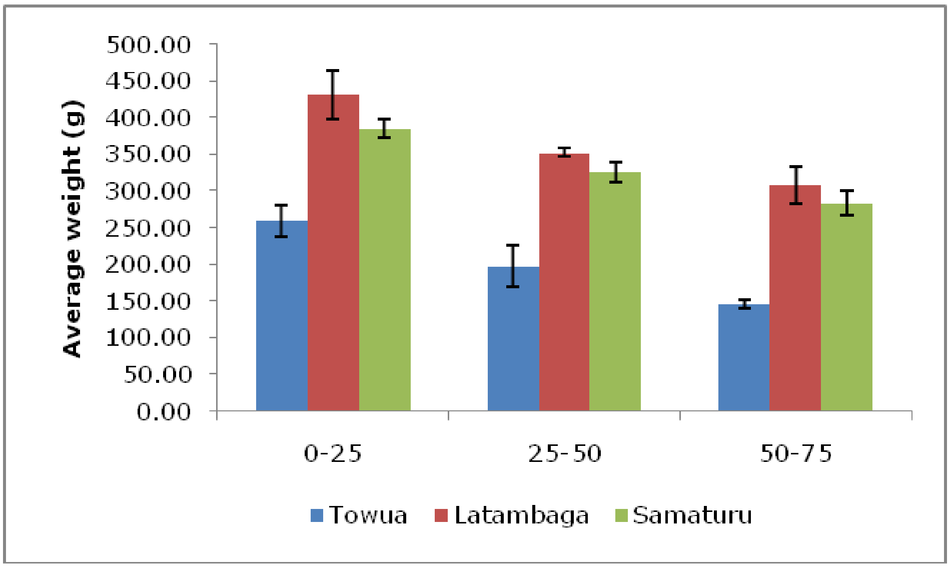

Figure 3. Average weight growth (g) at 45 days of cultivation.

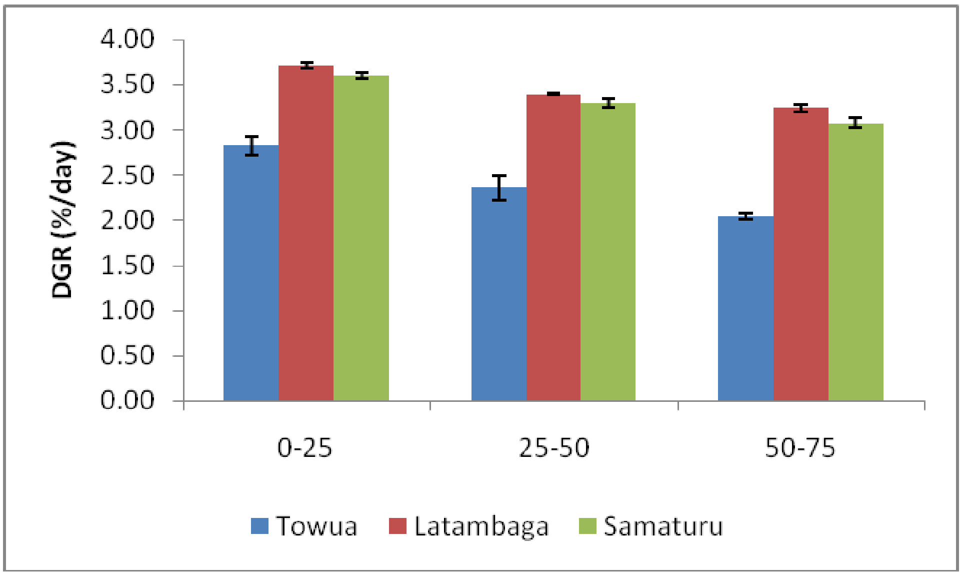

Figure 4. Daily growth rate (DGR) (% day^{-1}) at 45 days of cultivation.

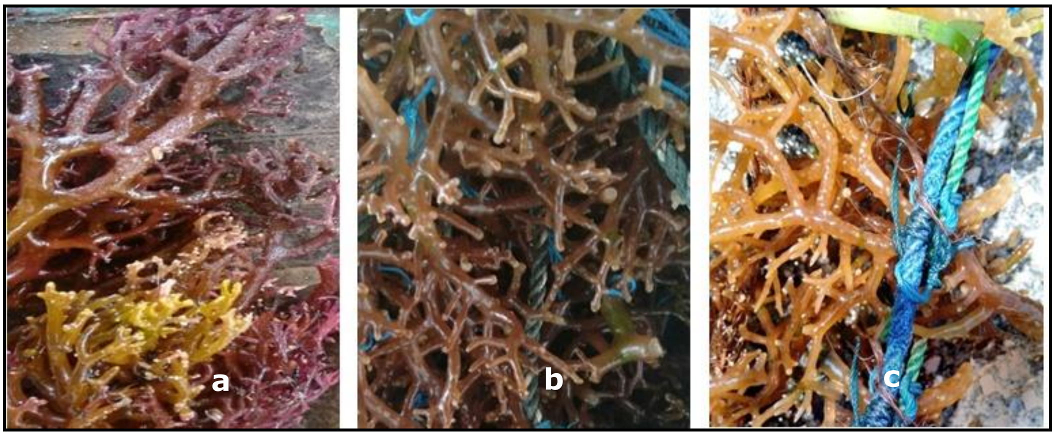

Figure 5. Colours of test seaweeds; a - Latambaga; b - Towua; c - Samaturu.

The results showed significant differences ($p<0.01$) in the average weight and daily growth of seaweed based on depth. The results of the average weight and DGR showed that the highest yield was obtained at 0-25 cm depth and the lowest at 50-75 cm depth for all the seaweed.

Carrageenan yield and gel strength. The carrageenan yield at depths of 0-25 cm, 25-50 cm and 50-75 cm was as follows: for Towua, 21.6±4.22%, 24.17±2.28% and 24.16±6.41%, respectively; for Latambaga, 22.94±13.35%, 22.02±11.46% and 19.96±0.99%, respectively; and for Samaturu, 18.68±3.21%, 23.48±0.54% and 15.84±2.41%, respectively (Figure 6).

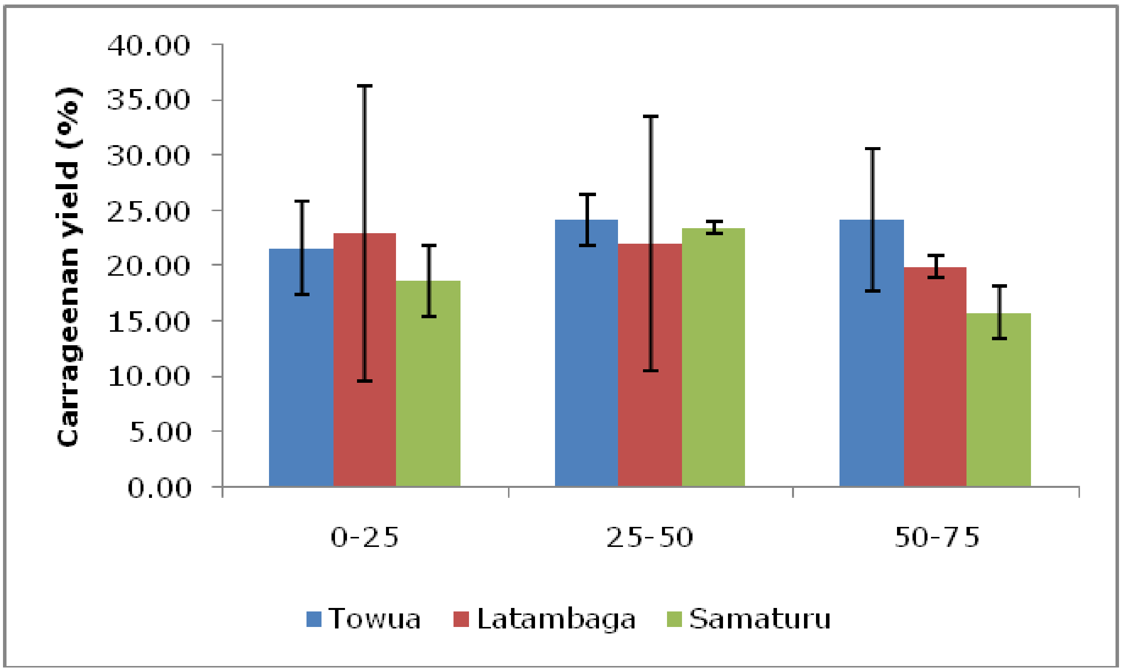

Figure 6. Carrageenan yield (%).

The statistical analysis showed no significant difference ($p>0.05$) between the depths on carrageenan yield. The highest carrageenan yield (24.17%) was obtained from Towua seedlings, at 25-50 cm depth. This is similar to the carrageenan yield of 24.16% recorded at 50-75 cm depth. Carrageenan yield did not show the same pattern at each depth as the average weight and DGR, but showed relatively similar patterns to the source of seaweeds. The highest carrageenan yield was obtained from seaweed seedlings from Towua village at a depth of 25-50 cm, followed by seedlings from Latambaga and Samaturu (Figure 6).

The gel strength of seaweed seeds at the depths of 0-25 cm, 25-50 cm and 50-75 cm was as follows: for Towua, 323.57±48.30 g cm^{-2}, 135.67±53.55 g cm^{-2} and 127.17±15.33 g cm^{-2}, respectively; for Latambaga, 299.88±50.96 g cm^{-2}, 268.21±44.54 g cm^{-2} and 261.04±51.26 g cm^{-2}, respectively; and for Samaturu, 181.13±26.43 g cm^{-2}, 170.81±75.22 g cm^{-2} and 115.59±9.20 g cm^{2}, respectively (Figure 7). The gel strength values for each of the seaweed seedlings showed a similar pattern for difference in depth as for the average weight and DGR. The gel strength value decreased with the increase in water depth. The highest gel strength value was observed in seeds sourced from Towua village at a depth of 0-25 cm, followed by Latambaga and Samaturu.

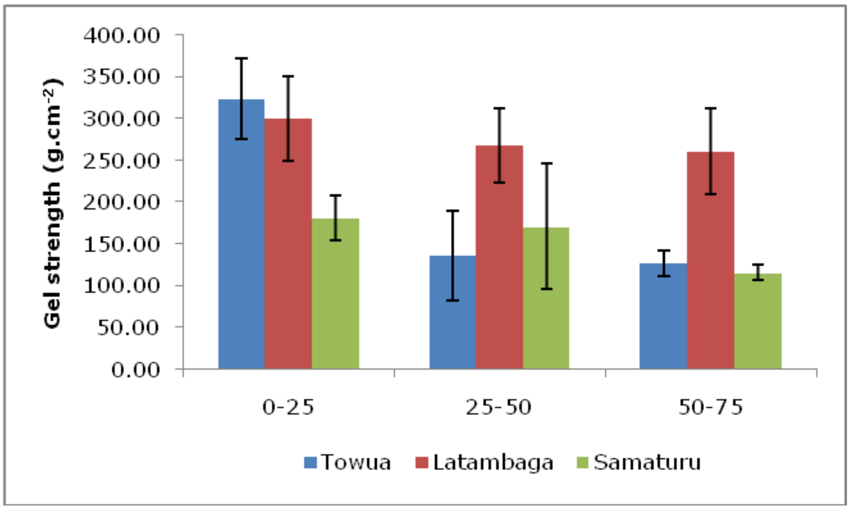

Figure 7. Gel strength (g cm^{-2}).

In this study, seaweed seedlings from Latambaga village produced the highest DGR compared to the others at a depth of 0-25 cm, and their growth decreased with the increase in water depth. Sufficient water movement can carry the nutrients required by plants for optimal growth. The genus *Kappaphycus* requires sufficient sunlight for its growth. Sunlight is also used as a source of energy to produce carbohydrates such as carrageenan and other commercially important substances (Sukiman et al 2014). Clear seawater allows sunlight to penetrate through to seaweeds that grow on the surface more easily than to those near the seabed or in deep water. The environmental conditions in the study area also supported this observation. In addition, the environmental conditions favoured DGR. The optimum water temperature for *Kappaphycus* spp. cultivation is in the range from 20 to 33°C (BSN 2011), whereas at the study area, it ranged from 30 to 32°C. At 0-25 cm depth, the maximum values for average weight and DGR were recorded because of the maximum penetration of sunlight in water, enabling photosynthesis. In general, the growth of seaweed in shallow waters is greater than in deeper waters, since in shallower waters seaweed can optimally utilise sunlight as a source of photosynthetic energy. Temperature and light play major roles in optimising the performance of seaweeds (Sukiman et al 2014).

This research was conducted during the rainy season, which affected the brightness, salinity, temperature and pH of the water. The difference in oxygen concentration occurs because of reduced photosynthetic activity, especially in deeper water (50-75 cm). Therefore, it is important to choose a location with sufficient sunlight intensity and clean seawater conditions to cultivate seaweed. At 0-25 cm depth, seaweed grows faster than at depths of 25-50 cm and 50-75 cm. This decrease is also due to differences in the nature of seeds or strains. Cornwall et al (2012) reported that any change in the pH of seawater can change the balance of the carbonate system and the concentration of inorganic carbon, which in turn affect the growth of seaweed, because it depends on the supply of inorganic carbon for photosynthesis (FAO 2017). According to Lavens & Sorgeloos (1996), the pH range for seaweed cultivation is 7-9, with an optimum from 8.2 to 8.7.

The minimum water salinity required for seaweed cultivation is approximately 28 ppt (Akib et al 2015). Hence, growth in front of river mouths or in brackish water will be hampered. In this study, the salinity ranged from 27 to 30 ppt at the site. Although the research was conducted during the rainy season, it did not significantly affect the growth of seaweeds. This is in line with Wenno et al (2015), who stated that the brown seaweed *K. alvarezii* has adaptive properties to both rainy and dry seasons and can live throughout the year.

Latambaga seedlings (approximately 40 km from Towua) produced the highest growth compared to Towua and Samaturu seedlings. Latambaga seedlings could have different characteristics, ecological conditions for growth and genetic variations compared to the seedlings from the other locations. In addition, these seeds were evaluated in a new location, which might have affected their growth. In some cases, seaweed cultivation in a new location results in higher growth compared to the old location, although there is no empirical evidence to support this claim in Towua village. Ramadhan et al (2018) reported that the location and physico-chemical parameters of waters affect seaweed production. According to Lobban & Harrison (1994), other interactions arise from biological parameters, such as age, phenotype and genotype, which affect the response of seaweed to the abiotic environment. These parameters can cause different responses in seaweed growth.

When the turbidity of the water is relatively high, the growth rate decreases with increase in depth. Research conducted by Paula & Pereira (2003) and Hayashi et al (2007) showed a decrease in the linear growth from a depth of 0.2 to 2 m for the brown tetrasporophyte strain of *K. alvarezii*. In addition, the yield and quality of the phycocolloids produced also varied, due to the influence of biological and environmental parameters, such as plant age, light, nutrition, temperature and salinity (Glenn & Doty 1990; Hayashi et al 2007). Different strains of seaweed do not have the same biological characteristics, and some strains can adapt better than others (De San 2012).

Water movement is a key factor affecting the growth of seaweeds. It plays an important role in preventing the increase in pH caused by the consumption of carbon dioxide and the supply of salt nutrients (Pantjara & Sahid 2008). The movement of water caused by currents is considered better than that caused by waves (https://www.fao.org/3/ab886e/AB886E01.htm). It is suggested that the appropriate water current for seaweed cultivation is approximately 20 cm s^{-1} (https://www.fao.org/3/ab886e/AB886E01.htm). The water current at the experimental location for seaweed cultivation was approximately 15-16 cm sec^{-1}, being suitable for transporting nutrients.

The colours of the seaweed seeds differed and produced different growth, carrageenan content and gel strength. *K. alvarezii* has the dominant pigments phycoerythrin and phycocyanin (Abfa et al 2013). The phycoerythrin pigment plays a role in capturing sunlight, which is used by chlorophyll-a in the photosynthetic process, affecting the quality of carrageenan (Dawes 1981). The above study revealed that the DGR value fluctuated and was influenced by the type of strain, depth, *in situ* ecology and water quality.

The highest gel strength were recorded in Towua seaweed. At 0-25 cm depth, the DGR value and carrageenan yield were highest for Latambaga compared to Towua and Samaturu seaweeds. The gel strength, however, was highest in Towua, followed by Latambaga and Samaturu. According to Parenrengi et al (2016), the DGR of seaweed culture at a depth of 0-30 cm has a strong correlation with carrageenan content, but a low correlation with gel strength. However, at a depth of 25-50 cm, the highest carrageenan yield was observed in the Towua seaweed, but had the lowest DGR value, followed by Samaturu and Latambaga seaweeds. According to Wenno et al (2016), reduced growth can increase the carrageenan yield along with an increase in water depth and also several other external and internal factors.

Towua seedlings were dark brown in colour, while Latambaga seedlings were light brown and Samaturu tended to be reddish, which could have affected the carrageenan yield and gel strength, especially for Samaturu seedlings. These seedlings did not reach the highest value for DGR, carrageenan yield, and gel strength. According to Munoz et al (2004), three varieties of *K. alvarezii* are cultivated in Mexico based on their colour, namely, green, brown and red, resulting in differences in the growth rate and carrageenan yield. The green colour resulted in a growth rate of 8.1%, brown 7.1% and red 6.5% per day, recording an carrageenan yield of 40.7%, 37.5%, and 32.7%, respectively. Wenno (2009) also showed that the carrageenan yield at a depth of up to 7 m was 17.12% for green species and 14.6% for brown species. Towua seeds are brown, appear darker and have a sturdy and comparatively large thallus that does not break easily. According to Patadjai (1993), seaweed containing a large amount of phosphate will have a stiff or hard thallus. In addition, the dark brown coloured seedlings absorb essential nutrients more efficiently, especially nitrogen and phosphorus, compared to light brown seeds. This observation is also in conformity with Affandi et al (2015), who reported that, in general, the dark coloured plants had more nitrogen content and yielded higher carrageenan than those with brighter and slightly red colour.

The carrageenan yield and gel strength from seaweed seedlings in Latambaga village at a depth of 0-25 cm was higher than those at depths of 25-50 cm and 50-75 cm. This is in accordance with the results of Failu et al (2016), which showed that a high concentration of carrageenan increased the gel strength. The increased carrageenan yield was caused by changes in the chemical composition of the tissue constituents and physiological responses that occur with increasing harvest age, in addition to the influence of water depth. Carrageenan is the main constituent of the polysaccharides of *K. alvarezii*. The amount varies depending on ecological factors (light, nutrients, surface waves, temperature) and the content of chemical compounds in marine algae, all of which are influenced by season, habitat, and plant age (Kreckhoff et al 2015). Good seaweed growth produces good-quality carrageenan and is influenced by water quality. Water quality in the experiment was in accordance with the requirement of life for seaweed cultivation.

The seaweeds of genera *Kappaphycus* and *Eucheuma* are commercially cultivated for carrageenan. Many factors influence the growth of seaweed and its chemical composition (Phang et al 2010). According to Hurtado et al (2008), stocking density, cultivation period and water depth affect the growth rate, carrageenan content and molecular weight of *Kappaphycus striatum* var. The highest carrageenan content was found at a depth of 20 cm (56.31%) and the lowest at 400 cm (17.10%) for *K. alvarezii* cultivated in Laikang village, Takalar Regency, South Sulawesi Province, Indonesia (Akmal et al 2014). In the present study, we found that carrageenan content decreased with increasing depth. The same result was obtained for seedlings of Latambaga village, but was not applicable to seedlings from Towua and Samaturu villages.

Carrageenan is located in the cell wall and intercellular matrix of seaweed tissue. It is a high molecular weight polysaccharide with 15 to 40% sulphate ester formed by alternative units of D-galactose and 3,6 anhydro-galactose (3.6 AG) combined with alpha-1,3 and beta-1,4-glycosidic bonds (Li et al 2014). The main differences that affect the properties of kappa, iota and lambda carrageenan are the number and position of sulphate ester groups and the content of 3.6 AG: a high sulphate ester content having a lower solubility temperature and lower gel strength (Necas & Bartosikova 2013). Temperature affects gel strength in seaweed culture, and gel strength decreases when the water temperature is lower or at higher depths, and increases when the water temperature is higher. The water temperature for seaweed cultivation should be between 20 and 33°C, which is the optimum temperature for *Kappaphycus* growth (BSN 2011), while at the site it was between 30 and 32°C.

According to Basmal et al (2005), the percentage of carrageenan is directly related to habitat, such as the intensity of sunlight, because it helps the process of carbohydrate formation. There is a very close relationship between the carrageenan yield and nutrients in the water (Amiluddin 2007), and the carrageenan yield in seaweed is directly related to the physical, chemical and biological environmental conditions in which the seaweed grows.

According to Abdan (2013) and Freile-Pelegrin (2006), the quantity and quality of carrageenan derived from marine cultivation varied greatly based on plant age, sunlight, nutrients, temperature, salinity and variety. Although the DGR value of Latambaga seedlings was higher than that of other seedlings, the carrageenan yield and gel strength were lower than those of Towua seedlings, presumably because there were differences in the strains and colours of the three seaweeds. According to Affandi et al (2015), the brown variety produces the highest carrageenan content, followed by green and red, but the gel strength is lower than that of the green variety. In the brown variety, it was indicated that the amount of carrageenan yield was directly proportional to the gel strength. Towua seedlings produced the highest carrageenan at a depth of 25-50 cm, followed by seedlings at 50-75 cm depth and the lowest at 0-25 cm depth. Burhanuddin (2012) showed that the highest carrageenan yield (41% at 60 cm depth) was recorded for *K. alvarezii* with initial seedling weight of 100 g, followed by 39.3% (30 cm depth) and the lowest 34% (90 cm depth). According to Wenno et al (2016), reduced growth can increase carrageenan yield with increased depth of water. Nursidi et al (2017) reported the highest carrageenan yield at a depth of 60 cm, compared to 10, 100, and 150 cm.

The gel strength of seedlings from all the locations showed the same pattern with respect to depth, the value decreasing with increasing water depth. Salinity also affects seaweed gel strength. Seaweeds with high salt content have lower gel strength, because the gel-binding capacity is smaller and the gel consistency is influenced by the type of carrageenan (Sormin et al 2018). The highest gel strength was observed in shallow water (0-25 m). In the tropical zone, the salinity at the surface is lower than that in deeper seawater (Darmadi 2010). Furthermore, salinity is a complex factor with two main components: osmotic potential and ionic composition. Osmotic potential affects the flow of water in and out of the cell due to turgor pressure, affecting the concentrations of Ca^{2+} and HCO^{3-}(Choi et al 2010). This affects the membrane integrity and photosynthesis. The hydrodynamic aspect of seawater movement is important for the survival of the thallus on a wave-swept coast and for the deposition of spores. It also has an important impact on the boundary layer above the plant surface, nutrient absorption and gas exchange (Kaandorp & Kübler 2001).

Although the gel strength treatment mechanism tends to be directly proportional to the proportion of carrageenan and salt concentrations, the use of excessive amounts of potassium salt results in a weaker gel strength (Morris et al 1980). For semi-refined carrageenan (SRC), gel strength increased with cooking time, cooking temperature, and potassium hydroxide concentration (for alkaline treatment, 30 min, 80°C, and 10% w/v KOH concentration) (Bono et al 2014). The concentration of solvent used in seaweed extraction affected the quality of carrageenan (Asikin et al 2015). The best yield and characteristics of carrageenan are at 7% KOH carrageenan extraction (Asikin & Kusumaningrum 2019). Harun et al (2013) reported that carrageenan with the best characteristics was found at the age of 30 days, whereas Wenno et al (2012) reported an age of 50 days for the best characteristics. Another factor that determines the quality of carrageenan is the extraction method using KOH, an alkaline solvent used for seaweed extraction, which produced good carrageenan quality and gel strength. Several other studies have shown that the difference in the solution used in the extraction process will affect the amount and quality of carrageenan and the strength of the gel produced (Table 2).

Table 2

Carrageenan and gel strength values reported in other studies at 45 days of cultivation

Location	*Solvent (%)*	*Carrageenan (%)*	*Gel strength (g cm^{-2})*	*Source*
Towua, South Sulawesi	KCl (0.2)	22.94	323.57	Present study
Bontang, East Kalimantan	KOH (7)	28.46	42.60	Asikin & Kusumaningrum (2019)
Manado, North Sulawesi	KOH (0.15) + KCl (1.25)	-	188.53	Erjanan et al (2017)
Tanimbar Maluku	KOH (12)	45,26	449.51****	Ega et al (2016)
Southeast Buton, Southeast Sulawesi	KCL (0.16)	69.81* 54.27 ** 43.29***	765.48* 826.28** 654.87***	Affandi et al (2015)
Letvuan, Southeast Maluku	NaOH (9)	43.25	207.50	Kumajayanti & Dwimayasanti (2018)

Note: * - brownish; ** - greenish; *** - reddish; **** - dyne cm^{-1}.

According to Hidayah et al (2013), the extraction of carrageenan using potassium hydroxide as a solvent results in a high carrageenan yield, because the cation+ potassium hydroxide combines with the carrageenan polymer chain to form kappa-carrageenan. This base solvent produces carrageenan with superior gel strength.

At the experimental site, hot and rainy weather affected the results of seaweed cultivation due to fluctuating environmental conditions. Therefore, experiments for more than a year are necessary to cultivate *K. alvarezii* and re-confirm results. Towua is relatively close to Latambaga (40 km) and Samaturu (80 km) in terms of the source of seaweed seeds as wild stock. This provides an opportunity to increase productivity under suitable ecological conditions for good-quality seaweed. However, it is also important to reduce problems that arise during the process of transporting seedlings when cultivation is done. The presence of several benthic coelenterate species in a water area can be an indicator of the suitability of aquaculture sites with good water movement, high levels of silicate phosphate, salinity, dissolved oxygen and intensity of sunlight (https://www.fao.org/3/ab886e/AB886E01.htm). This study indicated that the coastal village of Towua is an environmentally suitable location and has the potential to become a centre for seaweed cultivation in Kolaka Regency.

Conclusions. The highest DGR of *K. alvarezii* seaweed was recorded at Latambaga (6.99 g day^{-1}), followed by Samaturu (6.46 g day^{-1}) and Towua (3.34 g day^{-1}) at 0-25 cm depth. The highest carrageenan content was recorded at Towua (24.17%), followed by Samaturu (23.48%) and Latambaga (22.02%) at 25-50 cm depth. The gel strength obtained from seeds sourced from Towua, Latambaga and Samaturu, respectively, were 323.57 g cm^{-2}, 299.88 g cm^{-2} and 181.13 g cm^{-2}, at 0-25 cm depth. The site conditions where seedlings are sourced, varieties of seedlings and their properties cause differences in the growth rate, carrageenan content and gel strength. The water quality at the research site on the coast of Towua village qualifies it as a potential area for seaweed cultivation of *K. alvarezii*, which can become a centre for seaweed cultivation in Kolaka Regency.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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