J. Build. Mater. Struct. (2025) 12: 196-212 ***Original Article***
DOI : 10.34118/jbms.v12i2.4369

Assessing the Performance of Glueberry Fruit Powder as Viscosity Modifying Admixture for Self-Compacting Concrete Production

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Received:25-10-2025 **Accepted: 27-12-2025**

Abstract. Glueberry fruit powder has been used to enhance the viscosity of flour for the production of glutten-free biscuits with limited use for self-compacting concrete. It is for this reason that this study investigated the potential use of glueberry fruit powder as a viscosity modifying admixture for the production of self-compacting concrete. Both fresh and hardened properties were measured, at varying percentage addition levels of 0, 5, 10, 15 and 20% by weight of cement, and indicated as A_0 (control), B_5, B_{10}, B_{15} and B_{20} (experimental) respectively. A total of 120 cubes and 60 cylinders, were prepared and tested for the 7, 14, 28 and 90 days, curing phases. At a constant water/cement ratio and Conplast SP 430 addition, varied glueberry powder dosage caused an increase in setting times, plastic viscosity, flowability, passing-ability and segregation resistance, with further addition. Strength properties increased to maximum values at the 15% addition compared to the control and dropped with further addition in all curing durations. Water absorption decreased significantly to the 15% addition and marginally at the 20% addition compared to the control. The study recommended 15% glueberry fruit powder addition by weight of cement for the production of self-compacting concrete in hotter environments.

Key words: Glueberry fruit, self-compacting concrete, viscosity modifying admixture, compressive strength, split tensile strength, water absorption.

1. Introduction

Presently, the use of concrete material for the provision of housing in the construction industry has increased due to the rapid development of industrialisation and urbanisation (Yalley & Badu, 2018). Reports indicate that the global consumption or utilisation of concrete by the construction industry is estimated at approximately 17.5 billion metric tons per year (Bo, Yong & Chen, 2018). Concrete is a composite material comprising of cement, aggregates, water and at times admixture, mixed together, and cast to take the shape and texture of its formwork or mould, compacted on site, and allowed to harden under controlled conditions.

According to BS EN 12390-3 (2019) Code of Practice, the strength and durability characteristics of concrete is largely dependent on the cement, water and level of compaction as well as the gradation of the aggregates. Thus, in the view of Boutouam et al. (2024) it is for this reason, that the suitability of cement and water for concrete production is being extensively studied to ensure its ecological orientation for better strength, economic and environmental use. Cement is largely composed of lime (C_aO) and silica (S_iO_2), which reacts with each other and the rest of the constituents in the mix when water is added. According to Hassoun and Al-Manaseer (2015) this reaction forms combinations of tri-calcium silicate and de-calcium silicate referred to as C_3S and C_2S in the cement literature. These chemical reactions eventually generate a matrix of interlocking crystals that surround any inert filler (aggregates) and provides a high compressive strength and durability.

According to Boakye and Khorami (2023) for hardened concrete to obtain better strength and durability properties, independent of the quality of the constituent materials, one recommended solution, is the adoption of the right workability and compaction. Furthermore, the BS EN 12390-3 (2019) Code of Practice also recommends that a high degree of compaction without segregation should be ensured by providing suitable workability. The term consistency describes the wetness of the concrete mix, while plasticity describes the cohesiveness of the mix to hold the aggregates together by the cement paste. Too wet mix is difficult to be placed and causes segregation, hence the two terms are used to define concrete workability. Thus, Gambhir (2002) defined workability as the property of fresh concrete that determines the ease with which the mix can be worked with, and the amount of internal energy needed to achieve complete compaction. Compaction refers to the process of densifying concrete by pressing the constituent materials in the mix together into a close state of contact so that the entrapped air can be expelled from the concrete. It has been reported that a thorough compaction to eliminate most of the air pockets on the surface of the concrete is the basic necessity to successful concrete production, since the presence of even 5% voids in the hardened concrete due to incomplete compaction, may result in decrease in compressive strength by about 35% (Gambhir, 2002). Hence, from the mixing stage till it is transported, placed and compacted, Gambhir (2002) recommended that the mix should satisfy the following requirements: be able to produce a homogeneous fresh concrete from constituent materials, be cohesive and mobile enough to be placed and compacted. Zakka et al. (2015) reported that when the ideal workability is not achieved, concrete strength and durability properties are affected due to the lack of uniformity and complete compaction of the mix in the moulds.

To improve concrete workability to suit a particular design situation, various admixtures known as plasticizers and super-plasticizers, ranging from surfactants, soluble salts and polymers to insoluble materials, have been used in concrete production (Hameed et al., 2022). These admixtures allow the water content in the mix to be reduced without affecting its consistency or to increase its slump without changing the water content, or to achieve both effects at the same time (Hameed et al., 2022; Huang et al., 2024). On the contrary, other studies reported that the addition of plasticisers and super-plasticisers meant to improve concrete workability rather increase the risk of bleeding and segregation due to high fluidity and yield stress (Collerpardi, 2003; Leemann & Winnefeld, 2007; Hillal, 2021). Excessive bleeding and segregation in the mix according to Boutouam et al. (2024) result in low stability of the concrete mix, potentially affecting its strength and durability properties in the hardened state.

To control excessive bleeding and segregation in concrete during transport, placement and compaction, a new type of concrete known as self-compacting concrete (SCC) was developed at the University of Tokyo, Japan, in the late 1980s (Safiuddin et al., 2008; Boutouam et al., 2024). This new concrete, incorporating viscosity modifying admixtures (VMA) is designed to flow under the influence of gravity to a completely uniform level, filling the formwork and spaces between the reinforcement in clustered reinforced concrete without segregation (Khayat, 1998; Salahaldein, 2015; Hameed et al., 2022; Boakye & Khorami, 2023; Boutouam et al., 2024). Viscosity modifying admixtures with a suitable concentration of super-plasticisers (SP) not only increase the workability, viscosity and stability of the concrete mix, resulting in homogeneous dispersion of the constituent materials particles, but also retain the mixing water until the concrete hardens (Lachemi et al., 2004; Hameed et al., 2022; Boutouam et al., 2024).

Synthetic products such as vinyl-based and ethylene-based polymers as well as polymers derived from micro-organisms were the first functional viscosity modifying admixtures to be used, on a large scale in the production of self-compacting concrete in the construction industry (Abd et al., 2016; Yahia et al., 2020). Previous studies have demonstrated that the use of synthetic and micro-organism polymers such as welan gum, diutan gum and xanthan gum improve workability, viscosity and stability in concrete mix resulting in homogeneous dispersion of the constituent materials particles in self-compacting concrete (Ghio et al., 1995). However, other studies have also reported the negative effects associated with the use of synthetic products as viscosity modifying admixtures in the production of self-compacting concrete. These synthetic products or polymers are produced in chemical plants, involving petroleum-derived components that emit toxic gases, resulting in environmental pollution and increased cost in the production of self-compacting concrete (Zakka et al., 2015; Hameed et al., 2022; Boutouam et al., 2024).

For cost reduction and advancement in sustainable production of self-compacting concrete, researchers are exploring the potential use of viscosity modifying admixtures derived from plants, algae and animals as an alternative to the synthetic products. This move is consistent with the Green Building Technology (GBT) Concept which aims at using materials that are affordable, sustainable, non-toxic and ethical (Danso-Boateng, 2021). For instance, studies have shown that gum Arabic, derived from the exudates of acacia Senegal and acacia Seyal plants not only improve the workability, viscosity and stability but also increase the long-term strength and durability properties of self-compacting concrete than the control concrete (Zakka et al., 2025). Again, pre-treated rice husk ash used as viscosity modifying admixture, improved the workability, viscosity and stability as well as the long-term strength properties of self-compacting concrete (Fediuk et al., 2018). Furthermore, carrageenan, a biopolymer extracted from seaweeds and used as a viscosity modifying admixture, also improves workability, viscosity and stability of self-compacting concrete (Yahia, et al., 2020). In a recent study, it was demonstrated that 20% fly ash and 2% super-plasticiser improved the viscosity, flowability, filling/passing abilities, as well as segregation resistance of self-compacting concrete (Hameed et al., 2022). It is therefore evident that the use of plant and industrial based viscosity modifying admixtures is on the rise as they serve as an excellent alternative to the synthetic products for the production of low-cost and environmental-friendly self-compacting concrete. This notwithstanding, research institutions are still exploring local based materials from plant as viscosity modifying admixtures for the production of self-compacting concrete.

Glueberry plant, botanically known as Assyrian plum, comes from deciduous trees and belongs to the Cordia myxa species, and the Boraginaceae family. According to literature, the plant grows mainly in tropical zones in Africa, Asia, Australia and recently introduced in the Americas (Bhardwaj, 2024). The fruit extracts, according to studies contain some elements of oil, glycosides, flavonoids, sterols, saponins, terpenoids, alkanoids, phenolic acids, cocimarins, tannins, resins, gums, and mucilage (Al-Snafi, 2016). In the medical field, it is used as a versatile medicinal plant and additive with polyvalent functions. For instance, in Tanzania, the fruit pulp is applied to ringworm, in Mali the leaves were applied to wounds, and in the Comoros the powdered bark is applied to the skin in cases of broken bones before plaster was applied, to improve healing (Al-Snafi, 2016). Again, the plant mucilage powder used as muco-adhesive for the production of chlorhexidine buccal tablets was studied as a substitution for synthetic polymers, and found to have increased significantly the muco-adhesiveness of the tablets (Moghimipour et al., 2012).

Again, glueberry fruits contain fibres, biological compounds, proteins and carbohydrate supplements which makes the extracts a versatile additive with polyvalent functions in the cosmetic and food industries (Bhardwaj, 2024). For example, the effect of glueberry fruit extracts on the physico-chemical properties of topical cream formulation was studied. It was reported that the incorporation of the fruit extracts improved the consistency, viscosity, physical stability and Ph of the cream (Karamil, et al., 2015). Furthermore, the pasting properties of flour blended with glueberry fruit mucilage for the production of glutten-free biscuits with enhanced nutritional profile was investigated. It was found that the setback viscosity of the flour blends improved with further addition of the fruit mucilage (Saeed et al., 2022). However, the consistency, viscosity and stability roles of glueberry fruit powder as a viscosity modifying admixture for the production of self-compacting concrete has not been investigated yet. Therefore, the aim of this study was to investigate the potential use of the glueberry fruit powder as a viscosity modifying admixture on the physical, self-compacting, strength and durability properties of self-compacting concrete mix and cubes.

2. Materials and Methods

2.1. Materials

Materials used for the preparation of the test samples for this experimental work included the following; cement, glueberry fruit, conplast SP 430, aggregates and water.

2.1.1. Cement

Ordinary Portland cement of grade 32N, was obtained from a local cement supplier and used in this study to prepare the concrete mixes, cubes and cylinders. This cement is locally produced by the Ghana Cement Company and branded as GHACEM. The cement quality complies with the requirements of BS EN 197-1 (2011) Standard Specifications. The fineness of the cement, sieved on a 90-micron sieve was 5.6% and the specific gravity was 2.91. Again, the major chemical compositions of the cement used were silica (20.13), aluminium oxide (4.52), iron oxide (3.70), calcium oxide (63.30), and magnesium oxide (1.80).

2.1.2. Glueberry Fruit

Glueberry fruits were used as the viscosity modifying admixture (VMA) to enhance the self-compacting properties of the concrete mix. Ripped glueberry fruits were harvested from the plants in a Forest Reserve located in Fielmuo, in the Sissala-West District of the Upper-West Region of Ghana.

2.1.3. Conplast SP 430

Conplast SP 430, a high-range water-reducing super-plasticiser was added to the concrete mix. This was meant to reduce the quantity of water needed for a given flowability. Conplast SP 430 is a chloride-free super-plasticising additive, supplied as a brown solution that disperses instantly in water. It disperses the fine particles in the mix, enabling the water content of the concrete mix to work more effectively. The Conplast SP 430 used had a pH of 6.9, water content of 16%, and alkali content 2%.

2.1.4. Aggregates

Aggregates of high-quality and conforming to BS EN 12620 (2019) Standard Specifications, were sourced in Wa in the Upper-West Region of Ghana. Sharp river sand of maximum size of 4.75 mm was obtained along the bank of a large river whiles crushed granite stones of maximum size of 10 mm diameter were also obtained from a local quarry site.

2.1.5. Water

Clean and drinkable tap water free from harmful substances was used to prepare the test samples. The water, supplied to the laboratory by the Ghana Water Company Limited (GWCL) conformed to BS EN 1008 (2002) Standard Specifications.

2.2. Testing Methods and Procedures

2.2.1. Glueberry Fruit Preparation

Ripped glueberry fruits were harvested (Figure 1), washed and sun-dried to constant weight. The dried fruits were manually broken or crushed into pieces using a hammer and a local grinding stone. The crushed pieces were further milled into very fine particle size (45-150 microns) using a cone crusher and a vibratory mill. Finally, the milled particles were sieved through a 60 μm aperture size sieve to obtain a very fine and uniform powder as shown in Figure 2.

Fig. 1. Ripped fruit

Fig. 2. Milled powder

2.2.2. Aggregates Suitability Assessment

The following suitability properties of the aggregates were investigated: organic impurities, specific gravity, water absorption, fineness modulus, grain size distribution, abrasion strength, flakiness and elongation indices. The tests were performed in conformity with BS EN 12620 (2019) Standard Specifications.

2.2.3. Mix Design

The mix design employed for the study conformed to established standard requirements of BS EN 206-9 (2010), EFNARC (2002) and EFNARC (2005) guidelines for self-compacting concrete, and some previous work in the area (Zakka et al., 2015; Salem et al., 2016). Oualit et al., 2022). Previous studies indicate that adequate workability and resistance to segregation is achieved in self-compacting concrete, when a suitable amount of super-plasticiser is used together with the viscosity modifying admixture (Hameed et al., 2022). Thus, to improve the mix workability and flowability, Conplast SP 430 was added as a constant dosage of 0.6 litres per 100 kg of cement based on trial mixes. To study the influence of the glueberry fruit powder (GFP) on the behaviour of the self-compacting, strength and durability properties, the glueberry fruit powder content was varied from 0, 5, 10, 15 and 20% by weight of the cement. The test samples were then indicated as A_0 for the control, B_5, B_{10}, B_{15} and B_{20} for the experimental samples with 5, 10, 15 and 20% glueberry fruit powder (GFP) contents respectively. A cement/aggregate ratio of 1:2:4/0.55 (cement: sand: granite stones/water/cement ratio) was used to prepare the concrete mix for a target cube strength of 25 N/mm^2.

The materials were batched and mixed using concrete mixer. The aggregates were put in the mixer and half of the mixing water blended with the Conplast SP 430 added, and mixed for about two minutes before the cement, in the case of the control, or cement/glueberry fruit powder, in the case of the experimental, were added. The remaining water was then added and mixed to a uniform colour and consistency for the self-compacting properties tests.

For the compressive strength, split cylinder tensile strength and water absorption tests, the concrete mixes were cast into steel moulds of size 150 mm and cylinders of size 150 mm diameter and 300 mm high. Each casting was done in two layers and gently compacted by vibration purposely to minimise air pockets. The moulds and their contents were covered with plastic sheets and kept in the laboratory for 24 hours. This was to prevent shrinkage cracking due to speedy water evaporation which tends to promote undesirable loose of moisture in the samples. After 24 hours, the test samples were de-moulded, immersed in clean water in a curing water tank and tested for the 7, 14, 28 and 90 days, curing phases. In all, a total of 120 number cubes and 60 number cylinders were cast and used for the study.

2.3. Physical and Self-Compacting Properties

The physical and self-compacting properties of fresh self-compacting concrete mix were assessed using different testing methods. The properties considered are setting time, plastic viscosity, flowability and segregation resistance. The setting time of the mix was determined in conformity with BS EN 196-3 (2000) Standard Specifications, whiles the self-compacting properties were assessed in line with EFNARC (2002) and EFNARC (2005) Standard Specifications.

2.3.1. Setting Time

The time period in which concrete paste is required to lose its plasticity is referred to as setting time. The Vicat method, using the Vicat Apparatus was employed to determine the setting times of the mix. Test blocks were made and the initial and final set needles were used to test the blocks for initial and final setting times respectively. This was determined from an average of three sets of test blocks for each type of the glueberry fruit powder (GFP) percentage addition blended cement pastes.

2.3.2. Plastic Viscosity

The V-funnel method was used to aid in the measurement of the plastic viscosity of the concrete mix. The trap door at the lower end of the V-funnel was tightly closed and the wet concrete mix poured into the funnel. After 5 minutes, the trap door was opened and the discharge time measured, that is, the time taken for the self-compacting concrete mix to flow within the V-funnel.

2.3.3. Flowability

The flowability or filling ability of the mix was assessed using the slump flow test method. A conical mould having a lower diameter of 200 mm, an upper diameter of 100 mm and a height of 300 mm was used to conduct the test. This test measures the average diameter of flowing concrete mix after the mould is lifted and the flow completely stopped.

2.3.4. Segregation Resistance

The passing ability of the concrete mix through obstacles was measured using the L-box test method. The vertical section of the L-box was filled with the concrete mix and the gate raised to allow the mix to flow into the horizontal section. The height of the concrete mix at the end of the horizontal section and the height of the remaining concrete mix in the vertical section of the L-box were denoted as H_2 and H_1 respectively. The passing ability of the mix was measured from the ratio of these two heights (H_2/H_1). Again, the stability of the concrete mix was determined using the screen stability test, also known as sieve segregation test.

2.3.5. Strength and Durability Properties

The strength and durability properties evaluated were the compressive strength, split cylinder tensile strength and water absorption. These three tests are considered very essential in concrete production for the fact that they give the hardened concrete its overall quality. These tests were performed in accordance with BS EN 12390-3 (2019) and BS EN 12390-6 (2019) Standard Specifications.

For the compressive strength test, the concrete cubes were crushed in the Compression Testing Machine (Figure 3) at the age of 7, 14, 28 and 90 days, curing phases. Similarly, the split cylinder tensile strength test of the concrete was conducted using the Universal Compression Testing Machine (Figure 4) at the 7, 14, 28 and 90 days, curing durations. For the water absorption test, the cured cubes were first dried to constant weights (M_1) and then completely immersed in clean water in a water tank for 24 hours. The cubes were removed from the water after the 24 hours, thoroughly cleaned and immediately weighed again (M_2). The percentage of water absorption was then computed from the differences in weight before and after the immersion.

Fig. 3. Cube being crushed

Fig. 4. Cylinder being crushed

3. Results and Discussions

3.1. Aggregates Properties

The aggregates physical and mechanical properties investigated are summarised and given in Table 1. From the results, all the values of the properties evaluated met the suitability ranges prescribed for both fine and coarse aggregates in BS EN 12620 (2019) Code of Practice.

Table 1. Summary of aggregate properties

Property	Sand	Granite stones	BS EN Ref
Bulk specific gravity	2.58	2.61	2.38 – 2.75
Apparent specific gravity	---	2.68	2.38 – 2.75
Water absorption	9%	1.7%	≤ 20%
Fineness modulus	3.9	6.4	2.0 – 8.0
Abrasion strength	---	25%	≤ 40%
Flakiness index	---	12.5%	≤ 15%
Elongation index	---	8.8%	≤ 10%

3.2. Physical and Self-Compacting Properties

3.2.1. Setting Time

The initial and final setting times of the glueberry fruit powder (GFP) paste are presented in Table 2 and plotted in Figure 5. Both initial and final setting times increased steadily with further addition of the GFP to 150 minutes and 321 minutes at the 20% GFP content compared to 108 minutes and 280 minutes recorded by the control pastes, representing 38.9% and 14.6% increased respectively. The results show that glueberry fruit powder used as viscosity modifying admixture retarded the setting times generally. However, the retarding effect was high with the initial setting time compared to the final setting time. This setting behaviour was anticipated because the more the GFP is added, the more viscous and flowy the paste becomes. The viscous and flowy nature of the concrete paste at the initial plastic stage was higher than at the final plastic stage, and this might have caused more delay in the initial setting time than the final setting time. The recorded values satisfied the BS EN 196-3 (2000) Standard requirements of not less than 30 minutes for initial setting time and not more than 600 minutes for final setting time for Portland cement mix.

Table 2. Effect of GFP on setting times

Paste	GFP (%)	Cement (%)	w/c ratio	Setting time (minutes)	
				Initial	Final
A_0	0	100	0.55	108	280
B_5	5	100	0.55	119	296
B_{10}	10	100	0.55	128	304
B_{15}	15	100	0.55	141	313
B_{20}	20	100	0.55	150	321

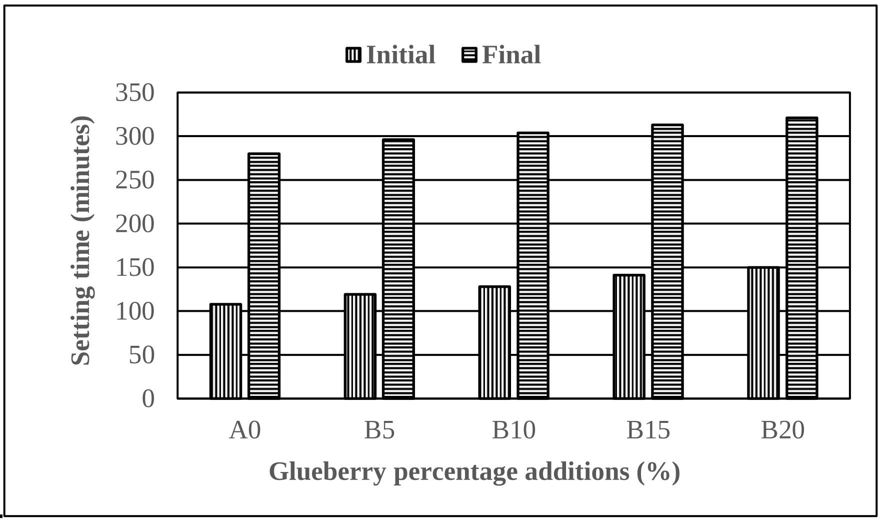

Fig. 5. Variation of setting times with GFP content

3.2.2. Plastic Viscosity

The plastic viscosity of the glueberry fruit powder (GFP) concrete mix was measured using the V-funnel flow time. From the results presented in Table 3, it can be observed that the flow time values decreased steadily with further addition of the GFP up to the 20% content. The control mix recorded a flow time of 8.30 seconds and this decreased significantly to 6.10 seconds at the 20% GFP content. This shows that plastic viscosity of the mix improves with increasing addition of GFP content as a viscosity modifying admixture. This result is consistent with results of other studies that used plant-based extracts as viscosity modifying admixtures for the production of self-compacting concrete. Previous studies have reported that plant-based viscosity modifying admixtures with suitable blends of high-range water-reducing super-plasticisers improve self-compacting concrete mix viscosity (Boutouam et al., 2024). The flow times are within the EFNARC (2002) and EFNARC (2005) prescribed permissible values of between 6 and 12 seconds for self-compacting concrete, and thus satisfy viscosity class VS1/VF1 requirements.

Table 3. Effect of GFP on the properties of SCC mix

Mix	V-funnel time (sec)	Slump flow (mm)	T_{500} mm time (sec)	L-box	Segregation index (%)
A_0	8.30	740	3.10	0.82	6.4
B_5	7.40	717	3.40	0.86	6.8
B_{10}	6.60	709	3.80	0.90	7.10
B_{15}	6.50	684	3.90	0.96	7.30
B_{20}	6.10	652	4.00	0.99	7.90

3.2.3. Flowability

The degree of the flowability of the concrete mix was measured using the slump flow test, whiles the time required for the concrete mix flow to reach a circle with a 500 mm diameter was measured using the T_{500} mm test. From the results presented in Table 3, the slump flow diameter values obtained are 740, 717, 709, 684 and 652 mm for the A_0, B_5, B_{10}, B_{15} and B_{20} mixes respectively. This reduction in the slump flow values may be attributed to increased viscosity of the mix influenced by the GFP percentage additions. The allowable slump flow diameter values for self-compacting concrete mix specified by EFNARC (2002) and EFNARC (2005) ranges between 600 and 800 mm, hence all recorded values fall within the suitability range.

Again, from Table 3, the time of flow (T_{500}) measured for the concrete mix to reach a spreading diameter of 500 mm increases as the slump flow diameter values decrease. The time of flow values obtained for all the concrete mixtures conformed to the EFNARC (2002) and EFNARC (2005) guidelines for self-compacting concrete. It has been established that a lower time of flow between 3 and 7 seconds, show higher flowability (Buari et al., 2019). Therefore, from the flowability point of view, all the mixes have good consistency and workability.

3.2.4. Segregation Resistance

The segregation resistance of the mix was evaluated using the L-box and screen stability tests. Table 3 presents the results of the H_2/H_1 ratios for the L-box test. From the results, the values of H_2/H_1 ratios increased from 0.82 at the control mix to 0.99 at the 20% GFP addition content. This increased in values can be linked to the viscous nature of the mix influenced by the GFP, which led to low frictional resistance within the mix and hence, increased the passing ability. The passing ability of all the mixes met the EFNARC (2002) and EFNARC (2005) recommended H_2/H_1 ratio range of not less than 0.8 and not more than 1. A mix is described as having a good passing ability when the blocking ratio is close to 1, and a high viscosity when the blocking ratio is less than 0.80 (Hameed et al., 2022).

In a similar trend, the screen stability test obtained an increased percentage values of 6.4, 6.8, 7.10, 7.30 and 7.90% for the A_0, B_5, B_{10}, B_{15} and B_{20} mixes respectively. The results showed good improvement in segregation resistance with increasing content of GFP percentage addition. Hence, all the mix compositions of the self-compacting concrete could be described as stable because the stability percentage values are all within the range of 0 to 15% recommended by EFNARC (2002) and EFNARC (2005).

3.3. Strength and Durability Properties

3.3.1. Compressive Strength

The results of the compressive strength of concrete cubes tested at the 7, 14, 28 and 90 days, curing phases are shown in Table 4 and plotted in Figure 6. From the results, concrete cubes with 15% GFP content obtained the highest strength in all curing durations. In 7 days curing phase the control cubes obtained a compressive strength value of 14.70 N/mm^2 and increased to 18.13 N/mm^2 at the 15% GFP content, representing a 23% increased. In 14 days curing duration, compressive strength increased from 20.63 N/mm^2 at the control cubes to a maximum of 24.03 N/mm^2 at the 15% GFP addition, representing 16.5% increased. In a similar trend, compressive strength moved from 28.33 N/mm^2 and 33.96 N/mm^2 to 31.99 N/mm^2 and 36.30 N/mm^2, representing 12.95% and 6.9% at the 15% and 20% GFP addition levels respectively. Again, at the 15% GFP content, compressive strength increased from 18.13 N/mm^2 at 7 days curing phase to 36.30 N/mm^2 at the 90 days curing phase, representing 100% increased. Beyond the 15% GFP addition content, compressive strength declined in all curing durations.

Table 4. Compressive strength of concrete cubes (N/mm^2)

Cube	7 days			14 days			28 days			90 days		
	value	Mean	SD	Value	Mean	SD	Value	Mean	SD	Value	Mean	SD
A_0	14.66	14.70	0.327	20.80	20.63	0.409	28.29	28.33	0.426	33.68	33.96	0.270
	15.04			20.16			28.77			33.97		
	14.39			20.92			27.92			34.22		
B_5	16.83	16.76	0.204	22.19	22.18	0.195	28.72	29.40	0.598	34.60	34.59	0.320
	16.92			21.98			29.66			34.27		
	16.53			22.37			29.83			34.91		
B_{10}	16.99	17.17	0.170	22.90	22.57	0.504	30.11	30.55	0.573	34.96	35.19	0.230
	17.18			22.82			31.20			35.42		
	17.33			21.98			30.35			35.19		
B_{15}	18.34	18.13	0.221	24.00	24.03	0.242	31.74	31.99	0.223	36.63	36.30	0.397
	18.16			23.81			32.16			35.86		
	17.90			24.29			32.08			36.41		
B_{20}	17.98	17.82	0.364	22.67	23.17	0.527	30.98	31.02	0.227	36.13	35.67	0.581
	18.07			23.11			30.81			35.02		
	17.40			23.72			31.26			35.87		

The high compressive strength development from the control cubes to the 15% GFP addition content cubes in all the curing durations, and the significant 100% increased from 7 days curing phase to the 90 days curing phase could be attributed to the gum and mucilage properties of the GFP. Gum and starchy plant-based viscosity modifying admixtures, according to studies, improve workability and density thereby promoting early strength development (Boutouam et al., 2024).

Again, the significantly higher percentage increase of the compressive strength from the 7 days curing duration, to the 90 days curing duration at the 15% GFP content was largely due to increased flowability, passing ability and segregation resistance of the mix. This led to minimal void formation resulting in higher strength gain with prolonged curing duration.

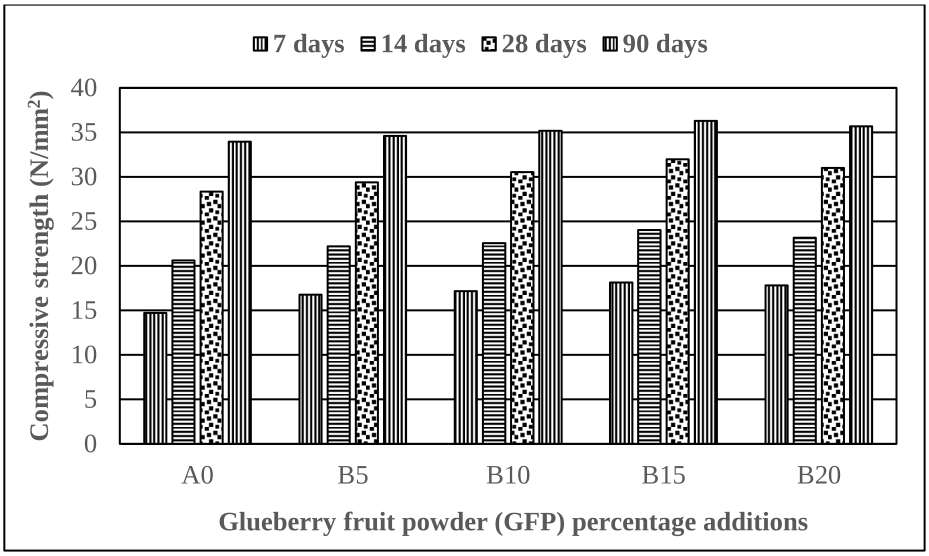

Fig. 6. Variation of compressive strength with GFP content and curing duration

In addition to the descriptive statistics, an analysis of variance (Two-way ANOVA) test was performed. This was purposely to determine the contribution of GFP and curing duration to the compressive strength behaviour. From the predictive values shown in the model summary in Table 5, it could be observed that curing duration contributed significantly higher, $F(1,40) = 6883.462$, $p < 0.05$, than the GFP, $F(1,40) = 126.223$, $p < 0.05$. Again, the R-square value ($R^2 = 0.998$) suggests that 99.8% of the variation in the compressive strength data can be explained by the GFP content and curing duration.

Table 5. ANOVA analysis of compressive strength of GFP cubes data (N/mm²)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	3019.192[a]	19	158.905	1114.757	0.000
Intercept	41210.508	1	41210.508	289101.867	0.000
GFP	71.971	4	17.993	126.223	0.000
Duration	2943.644	3	981.215	6883.462	0.000
GFP x Duration	3.577	12	0.298	2.091	0.040
Error	5.702	40	0.143		
Total	44235.401	60			
Corrected total	3024.894	59			

a. $R^2 = 0.998$ (Adjusted $R^2 = 0.997$)

3.3.2. Split Cylinder Tensile Strength

Table 6 and Figure 7 present the results of the split cylinder tensile strength of the self-compacting concrete prepared with glueberry fruit powder (GFP) as viscosity modifying admixture. Split cylinder tensile strength increased steadily up to the 15% GFP content and dropped with further addition in all curing durations. This strength behaviour by the concrete cylinders is similar to that exhibited by the compressive strength of the cubes. For instance, the percentage increase of split cylinder tensile strength values from the control cylinders to the 15% GFP content in 7, 14, 28 and 90 days, curing durations were 50%, 25.4%, 30.5% and 18% respectively. However, unlike the compressive strength, the increased in split cylinder tensile strength from the 7 days curing duration to the 90 days curing duration at the 15% GFP content was 45%. The high split tensile strength at the 15% GFP content maybe due to the improved self-compacting properties of the mix influenced by the addition of the glueberry fruit powder.

Table 6. Split cylinder tensile strength of concrete cylinders (N/mm²)

Cylinder	7 days			14 days			28 days			90 days		
	value	Mean	SD	Value	Mean	SD	Value	Mean	SD	Value	Mean	SD
A_0	2.71	2.76	0.151	3.88	3.78	0.246	4.09	4.23	0.140	4.98	5.00	0.410
	2.93			3.50			4.37			4.60		
	2.64			3.96			4.22			5.42		
B_5	2.99	2.97	0.181	3.93	3.95	0.141	4.80	4.82	0.136	5.17	5.27	0.299
	3.14			4.10			4.69			5.61		
	2.78			3.82			4.96			5.04		
B_{10}	3.34	3.37	0.222	4.32	4.20	0.120	4.97	5.12	0.337	5.91	5.79	0.125
	3.17			4.08			5.51			5.66		
	3.61			4.20			4.89			5.80		
B_{15}	4.00	4.15	0.175	4.71	4.74	0.152	5.37	5.52	0.145	5.90	5.92	0.067
	4.34			4.60			5.66			5.86		
	4.10			4.90			5.52			5.99		
B_{20}	3.88	3.76	0.295	4.33	4.35	0.149	5.50	5.45	0.095	5.58	5.69	0.110
	3.97			4.50			5.51			5.69		
	3.42			4.21			5.34			5.80		

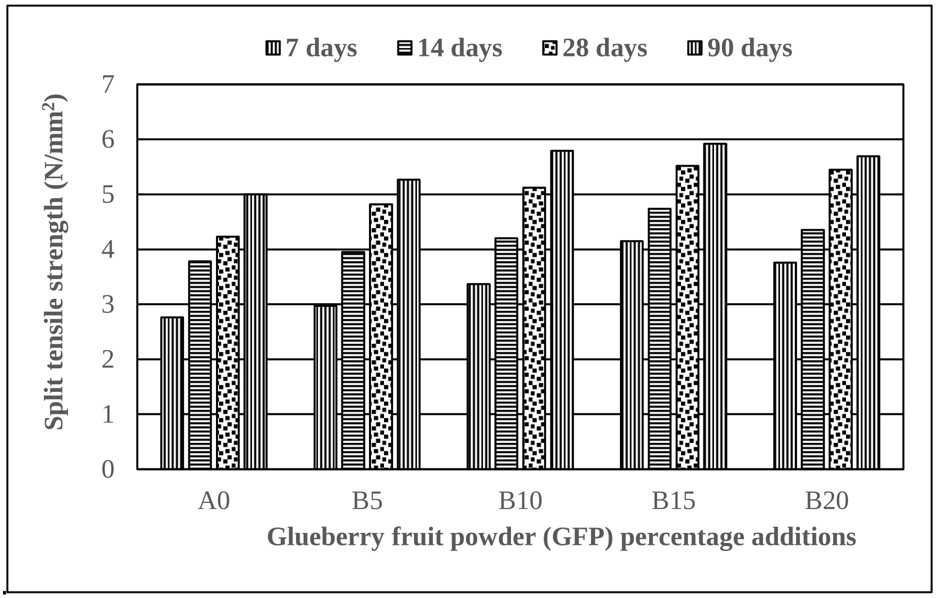

Fig. 7. Variation of split cylinder tensile strength with GFP content and curing duration

The statistical test results presented in Table 7, yielded P-value of 0.000 for both GFP content, $F(4,40) = 58.431$, $p < 0.05$, and curing duration, $F(1,40) = 316.291$, $p < 0.05$. Since the variance ratio (F) value for curing duration is very high (316.291) than that of the GFP content (58.431), it implies that curing duration contributed far more to the split tensile strength data than the GFP content.

Table 7. ANOVA analysis of split cylinder tensile strength of GFP data (N/mm²)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	50.120[a]	19	2.638	63.322	0.000
Intercept	1237.332	1	1237.332	29701.901	0.000
GFP	9.736	4	2.434	58.431	0.000
Duration	39.528	3	13.176	316.291	0.000
GFP x Duration	0.855	12	0.071	1.710	0.101
Error	1.666	40	0.042		
Total	1289.118	60			
Corrected total	51.786	59			

a. $R^2 = 0.968$ (Adjusted $R^2 = 0.953$)

Again, the R-square statistics generated by the model indicates that 96.8% (R^2 = 0.968) of the variation in the split cylinder tensile strength data can be linked to GFP content and curing duration. With this high explanatory power of the model, the reliability of the data could be described as excellent and valid up to the 15% GFP addition content in all curing durations.

The Pearson Product-Moment Correlation test was also performed to determine the degree of association between the split cylinder tensile strength and compressive strength of the cubes made with the glueberry fruit powder as a viscosity modifying admixture. From the correlation analysis presented in Figure 8, about 99.5% of the increased in the split tensile strength (r = 0.9946, N = 5, $p < 0.05$) could be explained by the increased in the compressive strength. That is, compressive strength increased with a corresponding increase in split tensile strength.

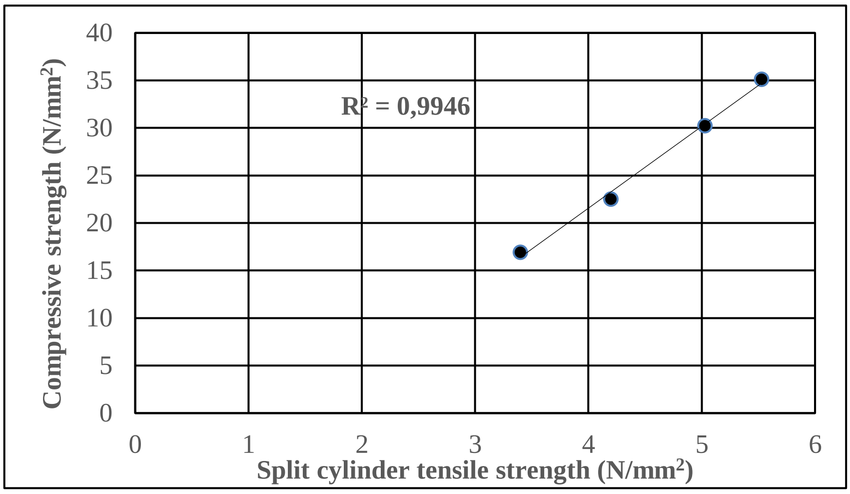

Fig. 8. Relationship between split cylinder tensile strength and compressive strength

3.3.3. Water Absorption

The results of the water absorption of the concrete cubes are presented in Table 8 and plotted in Figure 9. Water absorption decreased steadily with increasing percentage addition of the glueberry fruit powder (GFP), and curing duration. For instance, in 7 days curing duration, the control cubes recorded water absorption rate of 11.72% and decreased to 9.41% at the 20% GFP addition content, representing 24.5% decrease

Table 8. Water absorption of concrete cubes (%)

Cube	7 days			14 days			28 days			90 days		
	value	Mean	SD	Value	Mean	SD	Value	Mean	SD	Value	Mean	SD
A_0	10.22	11.72	1.408	11.50	11.62	0.115	10.60	11.01	0.376	10.70	10.84	0.123
	13.01			11.62			11.09			10.89		
	11.94			11.73			11.34			10.93		
B_5	11.43	11.49	0.191	11.07	10.99	0.279	10.55	10.55	0.155	10.10	10.11	0.091
	11.70			11.22			10.71			10.21		
	11.33			10.68			10.40			10.03		
B_{10}	10.20	10.22	0.136	9.97	9.95	0.161	9.60	9.61	0.260	9.27	9.22	0.123
	10.36			10.10			9.88			9.08		
	10.09			9.78			9.36			9.31		
B_{15}	10.03	9.90	0.184	9.61	9.51	0.105	9.01	8.92	0.107	8.60	8.54	0.079
	9.98			9.40			8.94			8.45		
	9.69			9.52			8.80			8.57		
B_{20}	9.24	9.41	0.165	9.03	9.15	0.151	8.30	8.29	0.145	7.40	7.37	0.266
	9.57			9.32			8.14			7.09		
	9.41			9.10			8.43			7.62		

In 90 days, the control cubes absorbed 10.84% water and decreased to 7.37% absorption at the 20% GFP addition level, representing 47.1% absorption decrease. In 90 days, the control cubes absorbed 10.84% water and decreased to 8.54% at the 15% GFP content cubes, representing 27% decreased, and 15% decreased at the 20% GFP content addition cubes. It is clear that the cubes experienced significant reduction in water absorption up to the 15% GFP content, and thereafter, experienced marginal reduction at the 20% GFP content addition cubes. The steady reduction in water absorption as the GFP content and curing duration increased can be attributed to the finer nature of the GFP particles coupled with the gum and mucilage properties. This enabled the concrete mix to flow to fill all voids within the cube structure and as the curing duration is increased, the denser and less permeable the concrete becomes. In a previous study using groundnut shell ash as viscosity modifying admixture, it was observed that the water absorption of the concrete steadily reduced with further addition of the ash, as well as with extended curing duration (Buari et al., 2019).

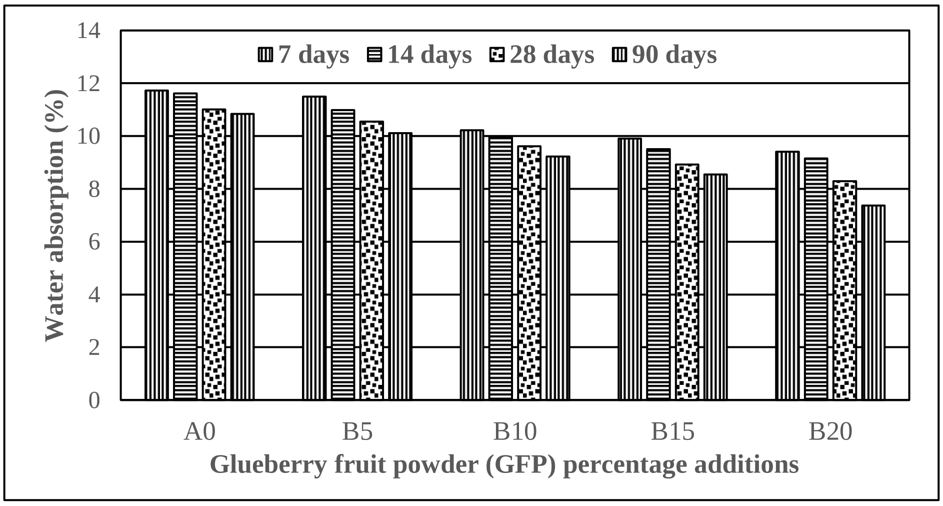

Fig. 9. Variation of water absorption with GFP content and curing duration

Again, to assess the contribution of GFP and curing duration to the water absorption behaviour, an analysis of variance (Two-way ANOVA) test was performed. From the results, both factors recorded P-values of 0.000, that is, GFP, $F(1,40) = 114.909$, $p < 0.05$, and curing duration, $F(1,40) = 39.972$, $p < 0.05$ (Table 9). The results showed that both factors influenced the water absorption data. However, unlike the strength properties, it can be noticed that GFP content contributed far more to the water absorption data than curing duration. Based on the discussions of the descriptive statistics results, this outcome was expected. The R-square statistics generated by the model reveals that 93.7% ($R^2 = 0.937$) of the variation in the water absorption data can be attributed to the GFP and curing duration.

Table 9. ANOVA analysis of water absorption of GFP cubes data (%)

Source	Sum of squares	df	Mean square	F-value	P-value
Model	77.914[a]	19	4.101	31.188	0.000
Intercept	5905.376	1	5905.376	44912.926	0.000
GFP	60.435	4	15.109	114.909	0.000
Duration	15.767	3	5.256	39.972	0.000
GFP x Duration	1.712	12	0.143	1.085	0.398
Error	5.259	40	0.131		
Total	5988.550	60			
Corrected total	83.173	59			

a. $R^2 = 0.937$ (Adjusted $R^2 = 0.907$)

4. Conclusions

The main aim of this study was to investigate the potential use of glueberry fruit powder (GFP) as a viscosity modifying admixture on the physical, self-compacting, strength and durability properties of self-compacting concrete. At a constant cement content, water/cement ratio and Conplast SP 430 dosage, GFP increased the setting times of the paste with further percentage addition. The self-compacting properties of the fresh concrete mix (plastic viscosity, flowability and segregation resistance) improved significantly with further addition of the GFP especially at the 15% and 20% percentage addition contents.

The concrete cubes and cylinders obtained maximum strength values at the 15% GFP addition content. Beyond the 15% GFP addition, both compressive and split cylinder tensile strengths declined for all curing ages. This means the GFP content was sufficient to fill the voids at the 15% addition content. Beyond the 15% GFP content there was excess resulting in the decline in strengths. Again, at a constant glueberry fruit powder (GFP) percentage addition, compressive and split cylinder tensile strengths increased as the curing duration increases. This implies that the GFP used as viscosity modifying admixture works better with age. Water absorption of the concrete cubes decreased with further addition of the GFP and increased curing duration. This may be attributed to the high fine particles, gum and mucilage properties of the GFP, which increased the concrete density, thus making the cubes less permeable to water. The decrease of water absorption of the cubes with age of curing may also be linked to concrete maturity.

The contribution of GFP and curing duration to the compressive strength, split cylinder tensile strength and water absorption data were predicted using the ANOVA. The statistical analysis indicate that both factors contributed to strength and water absorption behaviour. Whiles curing duration influenced more of the strength behaviour, the GFP additions also influenced more of the water absorption behaviour. The relationship between the compressive strength and split cylinder tensile strength was also analysed. The regression coefficient (R^2) is 0.9946, implying that compressive strength explains 99.5% of the variability in the split cylinder tensile strength data.

The study therefore concludes that with a suitable water/cement ratio and conplast SP 430 dosage, further addition of GFP up to 20% in the concrete mix increased setting times and improved the self-compacting properties of fresh self-compacting concrete mix. The addition of GFP in the mix also reduced significantly the water absorption of the concrete up to the 20% addition content. For strength considerations, the study recommends 15% GFP addition by weight of cement as a viscosity modifying admixture for self-compacting concrete production especially in windy and hotter environments.

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